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ASSESSING EFFECTIVENESS OF VARIOUS SOIL MOISTURE CONSERVATION TECHNIQUES ON MAIZE YIELD IN ZAKA DICTRICT

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I, Noel Mapope, formally declare to Bindura University of Science Education that this research project reflects my original research work. It is submitted as part of the requirements for the award of the Bachelor of Agricultural Science Honors Degree in Crop Science .This research's findings have never been submitted in any other institution.

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Supervisor

I have supervised the research project for the above mentioned student and I am convinced that the research can be submitted.

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ABSTRACT

Soil-water scarcity is the major constraint to rain-fed maize production in semi-arid Agro-ecological Region IV in Zimbabwe. The objective of this study was to determine four in- situ moisture- retention techniques namely tied ridges (TR), ridges (RD), potholing (PH) and flat land (FL, control) on a clay- loam Alfisol at ward 33, Zaka District (18°57′ S, 31°31′ E; 520 mm mean annual rainfall) during the 2024/25 season. A randomized complete block design with three replications was used. Data collected were soil moisture (0–15 cm, 15–30 cm), stem girth, plant height, 1000 seed weight and final grain yield measured at 3 weeks intervals and analysed using GenStat 17th generation. There were significant treatment effects ($p < 0.05$) on all variables. TR retained 23–48 % more soil moisture than FL throughout the season and maintained the slowest moisture decline. Consequently, TR recorded the largest stem girth (19 % greater), the tallest plants (22 % taller), the heaviest 1000 seed weight (17 % heavier) and the highest grain yield (4.26 tonnes per hectare) compared to RD (3.58 tonnes/ha), PH (3.41 tonnes/ha) and FL (2.77 tonnes/ha). The yield advantages were attributed to longer root zone water availability that increased photosynthate partitioning during grain filling. The results suggest tied ridging as a low cost, climate-smart practice capable of enhancing maize productivity by ≥ 50 % under erratic rainfall. Therefore, adoption of TR alongside site-specific soil and residue management is recommended for smallholder farmers in similar semi-arid environments to improve food security and climate resilience.

Key terms: scarcity, moisture, retention, techniques, climate and resilience.

DEDICATION

To my parents, who planted the first seeds of curiosity in my mind; to the determined smallholder farmers of Ward 33, whose everyday struggle nurtured this work and to the Almighty God, whose favour grew each step of the journey.

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LIST OF ABBREVIATIONS AND ACRONYMS

MCT	Moisture Conservation Technique
SSA	Sub-Saharan Africa
LSD	Least Significant Difference
NR IV	Natural Region IV
NGO	Non-governmental organisation
CA	Conservation Agriculture
TR	Tied Ridges
PH	Potholing
RD	Ridges
FL	Flat Land
WUE	Water Use Efficiency
FAO	Food and Agriculture Organization
IPCC	Intergovernmental Panel on Climate Change
EMA	Environmental Management Agency
CAN	Calcium Ammonium Nitrate

CHAPTER ONE: INTRODUCTION

Conservation agriculture (CA) is a climate smart agriculture system, focusing on optimizing crop productivity, minimizing land and water use as well as increasing soil health. Soil moisture conservation techniques is a part of the various soil moisture conservation systems. Many soil moisture conservation techniques reduce water evaporation, increase soil water infiltration and increase soil water retention capacity (Tuure *et al.,* 2021; Cong *et al.,* 2024). Some of the soil moisture conservation techniques such as mulching, cover crops, conservation tillage and tied ridging have improved soil moisture levels and have increased sustainable maize yield in semi-arid environments (Tuure *et al.,* 2021; Cong et *al.,* 2024). In addition, there are some areas that have been impacted by droughts and other climate variability, soil moisture conservation techniques are essential. Tied ridging which is the method of forming ridges to trap rain water and mulching which decreases soil surface evaporation and maintains soil temperature are useful in improving maize yield (El-Beltagi *et al.,* 2022). In Zimbabwe's Natural Region IV (NR IV), which experiences some of the frequent droughts and moisture stresses (FAO, 2021), the effects of climate change have exacerbated the necessity of soil moisture conservation techniques. An increasing number of studies have confirmed the effectiveness of several soil moisture conservation techniques to boost maize yield and use of water. Increasing temperatures and the number of extreme events demand adaptation and innovative soil moisture conservation practices in order to ensure food security in semi-arid areas such as Zaka District. Several studies have been conducted and have proven the significance of specific soil moisture conservation techniques such as potholing and mulching (El-Beltagi *et al.,* 2022; Cong *et al.,* 2024). In fact, the past studies reveal that these methods are beneficial for maize yield in the NR IV.

However, various researches should be conducted in order to test these methods in the current conditions and determine if they are still beneficial in improving soil moisture level and subsequently increase maize yield in Zaka District. Moreover, some soil moisture conservation techniques should be evaluated in the local area taking into consideration soil type, topography and rain fall conditions (El-Beltagi *et al.,* 2022; Cong *et al.,* 2024). In Zimbabwe, the government has introduced some soil moisture conservation techniques like potholing (commonly known as Pfumvudza) as a measure to reduce the effects of climate change on agriculture. Therefore, assessing the effects of these techniques in terms of the moisture level and the yield in Zaka District is vital. This research aims to evaluate the efficacy of different soil moisture conservation or retention techniques in increasing maize yields in Zaka District, contributing to the wider goal of sustainable agriculture in semi-arid regions. The study also investigates the effectiveness of various soil moisture conservation techniques namely ridging, tied ridging and potholing focusing on their role in improving maize yields. The findings will provide insights into the most suitable methods for enhancing water retention and yield sustainability in the face of climate variability.

1.2 BACKGROUND TO THE STUDY

In most parts of the world, climate change challenges such as warming, erratic rainfall and prolonged dry seasons necessitate the use of innovative agricultural strategies to ensure food security in semiarid areas. It is, therefore important to improve soil moisture retention because it alleviates water stress and improves crop yield in the long run. Conservation Agriculture (CA) practices that may include cover cropping, mulching and minimum tillage are being adopted widely to further improve soil water retention at the same time reducing evaporation losses and boost yields. Mulching has been shown to add soil organic matter, increase microbial activity and improve water infiltration rates which are critical for attaining high yields in maize and other cereals. (GU *et al.*, 2023; Frontiers, 2023). In Sub- Saharan Africa (SSA), agricultural systems are highly susceptible to fluctuating climate conditions with regions like Zimbabwe’s NR IV experiencing severe droughts. Natural Region IV is defined by annual rainfall below 650 mm, poor soil fertility and elevated temperatures making it necessary to adopt innovative practices that increase water use efficiency. Mulching maintains soil temperature and reduces evaporation hence creating a supportive environment for plant growth (Frontiers, 2023; Li *et al.*, 2021).

Despite these improvements, gaps still remain in understanding the locally adapted effectiveness of these techniques. Recent studies highlight the need for comprehensive strategies combining multiple moisture retention techniques tailored to specific agro-ecological conditions. Even though methods like potholing (Pfumvudza) are being promoted in Zimbabwe to mitigate climate changes impacts, their efficacy under current climatic conditions and against other techniques requires further evaluation (Gu *et al.*, 2023; Frontiers, 2023). This research intends to address these gaps by assessing the performance differences of soil moisture conservation or retention techniques on maize yields in Zaka District. The study will support the identification of sustainable approaches that improve food security and flexibility in semi-arid farming systems delivering evidence-based recommendations for decision-makers.

1.3 STATEMENT OF THE PROBLEM

Maize production in Zaka district is restricted by low and unreliable rainfall, poor soil fertility and drought that often causes crop failure and food shortages. Even though some soil moisture conservation methods like potholing, ridging, mulching and tied ridging have been promoted, there is little information on their performance under current climate change, how they interact with local soil types and rainfall and how they contribute to improved maize yields. Therefore, this study aimed to fill these knowledge gaps through evaluating the performance of soil moisture conservation methods in terms of their effectiveness in improving water use efficiency and maize productivity in semi-arid areas.

1.4 JUSTIFICATION OF THE STUDY

This study is significant to farmers, policymakers and agricultural extension workers in Zaka District and other semi-arid districts. The study contributes to building the evidence base of the effectiveness of the adopted soil moisture conservation techniques of potholing, tied ridging and ridging in enhancing maize yield under the harsh climatic conditions of Zaka District. Through evaluating the effectiveness of the techniques, the study will result in enhanced maize productivity, ensure food security and mitigate the effects of climate change in agricultural activities. In addition, the results of the study will enable policymakers to prioritize the allocation of scarce resources and make targeted interventions in case of drought-induced crop failure.

The study will add to the existing knowledge base through supplying comparative data on the effectiveness of various moisture retention or soil moisture conservation techniques in maize production under the peculiar agro-ecological and climatic conditions of Zaka District. Although the existing literature has revealed the importance of individual techniques, there is a dearth of information on the effectiveness of the combined application of these techniques and their effectiveness under such circumstances. The results will form a basis for subsequent studies aimed at promoting conservation methods to be applied in other semi-arid regions across the world.

1.5 STUDY OBJECTIVES

1.5.1 Main objective

To evaluate the efficacy of different soil moisture conservation techniques (MCT) on soil moisture.

1.5.2 Specific objectives

- To assess the efficacy of various moisture conservation techniques on soil moisture.
- To evaluate the effectiveness of different moisture retention techniques on maize growth physiological parameters (stem girth and plant height).
- To determine the influence of different moisture retention techniques on maize yield.
- To determine the effectiveness of different moisture conservation techniques on 1000-seed weight.

1.6 Hypotheses

- There is no statistically significant difference in soil moisture percentage between different moisture conservation techniques.
- There is no statistically significant difference in maize growth physiological parameters (stem girth and plant height) across different moisture conservation techniques.
- There is no statistically significant difference in maize yield resulting from different moisture retention techniques.
- There is no statistically significant difference in 1000-seed weight of maize cultivated under different conservation techniques.

CHAPTER TWO: LITERATURE REVIEW

2.1 MAIZE PRODUCTION

Maize (*Zea mays*) is the most widely grown cereal crop in the world which plays an important role in food security, industrial use and livestock feed. The world's maize production stands at around 1.2 billion metric tons in 2022, with the United States, China and Brazil the top producers (FAO, 2022). In sub-Saharan Africa, maize serves as the staple crop, accounting for more than 30% of the calories consumed in several countries. While the region only accounts for 7% of the world's maize production, smallholder farmers produce 70% of the maize in the region, practicing rain fed agriculture. The region's erratic rainfall and prolonged droughts have resulted in low yields (CIMMYT, 2021). Zimbabwe's crop production decreased by 25% during the 2019/2020 season because of an extended drought (FAO, 2020). Hence, the need for climate smart agriculture to ensure food security and improve food production has emerged.

Maize is Zimbabwe's main food crop, contributing significantly to food security and livelihood in the country. It occupies about 60% of the country's arable land. Smallholder farmers contribute to over 70% of the country's maize output. (Mutiro & Makurira, 2021). However, the average maize yield is between 0.7-1.2 tons per hectare compared to the global average of 5.5 tons per hectare (Moyo *et al.,* 2023). Zaka district is located in Masvingo Province and is characterized by agro-ecological Region IV and V. These regions are semi-arid zones with low and erratic rainfall (Less than 650 mm annually). The region faces significant challenges such as low and erratic rainfall, soil degradation, lack of irrigation and recurrent droughts which have caused a drop in maize yields (Muchena *et al.,* 2022). Hence, the country relies on rain-fed agriculture to a greater extent, contributing to low productivity and food insecurity. Therefore, there is a need for soil moisture retention practices to improve productivity and reduce the country's dependence on food imports.

2.2 Impacts of climate change on maize production.

The effect of climate change has disrupted the production of staple crops such as maize, rice and wheat worldwide, leading to low yields. Droughts, unpredictable rainfall, rising temperatures and floods have destroyed the livelihood of the majority of people who rely on agriculture as their main source of food and income. For instance, the Intergovernmental Panel on Climate Change (IPCC) indicated that maize yield will decline by 7.4% for every degree of temperature rise (World Bank

Climate Knowledge Portal, 2023; ReliefWeb, 2023). Agriculture in Zimbabwe is mainly rain-fed and therefore, the effect of climate change is more pronounced in the country. The semi-arid regions in Zimbabwe have erratic rainfall and frequent droughts, causing a drop in the production of the staple crops. For instance, maize, the main staple crop has experienced low yields in the last decade, with the country having to rely on maize imports. The increased temperatures in Zimbabwe have resulted in soil degradation and water scarcity, limiting productivity (UNDP, 2023; World Bank Knowledge Portal, 2023).

Being the dominant staple and a key driver of food security, maize in Zimbabwe has experienced frequent yield failures due to recurrent droughts. Between 2001 and 2016, climate driven droughts significantly reduced maize yields resulting in food shortages. A lot of farmers are shifting to cultivating drought resistant crops like sorghum and millet to reduce the challenges. Drought resistant crops are better to the country's changing climate (ReliefWeb, 2023; UNDP, 2023). Farmers in Zaka District are increasingly adopting small grains and moisture conservation methods like potholing to counteract these challenges. However compared to past years, current conditions indicate a notable reduction in production and increased reliance on external food aid (UNDP, 2023; ReliefWeb, 2023). Moisture conservation is important in semi-arid regions. Tied ridging, mulching and conservation tillage have been adopted by the farmers in the region to reduce the rate of water evaporation and increase the amount of water infiltrated in the soil. Moisture conservation has contributed to improved crop tolerance to drought, stable yields and food security in the water-scarce regions (World Bank Climate Knowledge Portal, 2023; UNDP, 2023).

2.3 Soil moisture conservation techniques

2.3.1 Ridging

Figure 2.1: Ridging

The process of raising soil structures (ridges) in the planting area and leaving space between (furrows) is referred to as ridging in maize planting. It assists in soil management and the efficient use of water. By creating ridges, ridging improves drainage because water runs off into furrows. Ridging creates conditions where the soil is more aerated and structured, leading to better root development, resulting in increased plant growth (CropWatch, 2024). Furrows can also collect rainwater in dry places, ensuring more availability of water for crops (Dai *et al.*, 2024). Additionally, ridges are oriented along the contour lines to prevent soil loss caused by run-off (CropWatch., 2024).

In Zimbabwe, ridging as a soil and water conservation method dates back to the 1990s. It was introduced to combat widespread use off ploughs and deforestation, which had affected traditional farming practices. This was during a period when there was a significant land degradation throughout the country. The most successful breakthrough in the adoption of ridging was contour ridging which was developed by E.D. Alvord to control water run-off and soil erosion in the commercial farm sectors and eventually in the smallholder farms. However, during the enforcement of ridging under the Natural Resources Act of 1941 there was resistance to adoption of ridging by farmers due to labor shortages, land loss and in the case of those in drought-prone areas, there was little need for it (Springer Plus, 2024; Maxapress, 2024). After independence there was a shift towards a participatory approach to soil conservation. Infiltration pits and conservation tillage were introduced in areas like Chivi and Masvingo province as part of the interventions (MDPI, 2024; Maxapress, 2024). Even though there have been increased yields and water conservation using ridging in some areas, the extent of adoption has been low. Challenges to adopting the technology include labor requirements, technical skill shortages and resource limitations. Zaka district in Masvingo province had relied on traditional methods such as bush fallowing and shifting cultivation to maintain soil fertility and reduce land degradation, but these were no longer sustainable with increasing population and limited land availability. Stream bank cultivation was also common but later accelerated erosion leading to significant soil loss along watercourses. Environmental regulations including Zimbabwe's Environmental Management Act (EMA) have since restricted these destructive practices. Farmers have now turned to sustainable techniques like ridging to ensure long term soil conservation and productivity (Mutanda *et al.*, 2021).

2.3.2 Tied ridging

Figure 2.2: Tied Ridging

Tied ridging is a water and soil conservation technique used worldwide, particularly in arid and semi-arid regions to reduce runoff, enhance water infiltration and enhance crop yields (Ndung'u *et al.,* 2023). The practice which involves creating small barriers across furrows to trap water is adopted widely in regions with low rainfall. Tied ridges help to reduce soil erosion and improve moisture retention, contributing to increased agricultural productivity. African countries which may include Kenya, Ethiopia and Tanzania have implemented tied ridging in semi-arid areas to overcome drought and water scarcity. The technique is practiced together with conservation practices like mulching and crop rotation to boost maize and sorghum production in rainfed systems thereby improving soil moisture retention while reducing soil degradation (African Union Development Agency, 2023).The government of Zimbabwe and NGOs introduced tied ridging as part of broader efforts to address declining agricultural productivity related to climate change. In the 1980s, food security programs promoted the practice and as time goes on, it spread across different districts through farmer education and pilot projects (African Union Development Agency, 2023). Tied ridging technique has become a key practice in districts that were prone to drought such as Midlands, Masvingo and Matabeleland. The practice is important in reducing the impacts of erratic rainfall on maize production (International Institute of Tropical Agriculture, 2023).

2.3.3 Conservation Agriculture

Conservation agriculture (CA) is a sustainable farming approach that integrates minimal soil disturbance, permanent soil cover and crop rotation as three foundation principles. It minimizes soil degradation caused by intensive tillage thereby promoting ecosystem services, making it a key practice for sustainable agriculture (Galvez-Ruiz and Cuadros-Tavira, 2022; Thierfelder *et al.*, 2017). Erratic rainfall, droughts and loss of soil nutrients have pushed the need for practices that improve soil moisture retention, enhance soil fertility and reduce greenhouse gas emissions. CA practices such as crop rotation, minimum tillage and soil cover were adopted to overcome these challenges globally. Its widespread adoption is further driven by the recognition that CA helps in overcoming climate change while improving food security (Kassam *et al.*, 2022; FAO, 2023). CA has shown promise in reducing erosion and improving water use efficiency in semi-arid regions of Africa where adoption is growing. These successes underscore its role in achieving sustainable agricultural systems (Friedrich *et al.*, 2022; USDA., 2024). The introduction of CA in Zimbabwe was motivated by the need to improve food security, reduce dependence on chemical inputs and restore soil health back to normal status (FAO, 2023). Pfumvudza, Zimbabwe's most important conservation agriculture program is also based on the principles of CA which are minimum soil disturbance, maintaining soil cover and crop diversification. It aims to attain higher yields by focusing on efficient input use, proper planting methods and soil conservation techniques. The program has gained tolerance due to its alignment with CA principles and its potential to solve food insecurity. (Kassam *et al.*, 2022). The program addresses key challenges such as food insecurity, low rainfall and soil erosion. Pfumvudza improves productivity in resource constrained areas and aligns with national goals to increase resilience to climate change reducing the dependency on food aid (Friedrich *et al.*, 2022). International bodies and donor agencies have supported raising up these initiatives through funding and technical assistance (FAO, 2023; Kassam *et al.*, 2022).

2.2.4 Potholing

Figure 2.3: Potholing

Potholing is a conservation agriculture technique whereby small, evenly spaced holes are dug into the soil to capture and retain rainfall or irrigation water. Potholes act as micro reservoirs that reduce runoff, enhance water infiltration and improve retention of soil moisture. The method is particularly useful in arid and semi-arid regions where water is scarce and rainfall is erratic (Zimbabwe Situation, 2020). The process involves digging ditches of about 15 ×15 cm in a grid pattern on a given field. The holes are spaced to maximize water capture and are sometimes supplemented with organic manure to increase soil fertility. Potholes are carefully aligned based on the local rainfall patterns and soil conditions. (Frontiers, 2024; Zimbabwe Situation, 2020). The technique creates an environment less favorable to weeds thereby reducing competition for nutrients and water. Moreover, it ensures that crops have access to moisture during dry spells increasing their survival chances and productivity. Potholing also reduce the need for synthetic fertilizers and herbicides which promote sustainable farming practices (Zimbabwe Situation, 2020). The technique has enhanced the reduction of unpredictable rainfall and increased maize and other crops yield. Potholing is currently being used in several districts and carried out through government and nongovernmental organizations (NGO) programs (Zimbabwe Situation, 2020).This farming technique is being practiced by the farmers because of the reduction in crop yield and maintenance of food security in dry weather conditions (Zimbabwe Situation, 2020).

In Zaka district, potholing has become a major aspect of climate-smart agriculture. The local farmers have reported an increase in crop yields and more capacity to survive dry weather conditions. The method is introduced by the government through training by different government bodies and NGOs like Zimbabwe Super Seeds. Potholing has become a critical method to ensure food security in the district (Frontiers, 2024; Zimbabwe Situation, 2020).

CHAPTER THREE: METHODOLOGY

3.1 Description of the study area

The study was conducted in Ward 33, Zaka District, Masvingo province, Zimbabwe about 86 km south east of Masvingo town. The study area falls under agro-ecological zone IV characterized by low annual rainfall (450 –650mm) falling between November and May and with frequent seasonal drought. The climate in this area is characterized by hot and dry conditions. The maximum temperatures range between 38 ^{o}C in October and minimum temperatures below 10 ^{o}C in June. The main agricultural activities in the study area are small scale livestock production, small grain production (rapoko, sorghum), poultry farming and communal irrigation schemes. Maize, rapoko and groundnuts are the major crops grown in the study area. The natural vegetation in the area is savanna woodlands but most have been cleared for agriculture purposes. The soils are coarse textured sand developed from granitic parent material and are moderately shallow to shallow (40 – 100 cm) depths. These soils have poor moisture retention capacities hence soil moisture conservation is important for maize production in the area. Sources of water for agricultural production are from seasonal rivers, boreholes and small scale communal irrigation schemes. Most farmers practice rainfed agriculture which is supplemented by irrigation in communal schemes during dry seasons.

3.2 Study design

The experiment followed a Randomized Complete Block Design (RCBD) with three replications per treatment. The study was carried out on a selected farm in Rwauya Village. The field was divided into three catena positions namely upslope, mid-slope and lower slope. Each catena position was divided into four soil moisture conservation treatments

1. Potholing (PH)
2. Ridges (RD)
3. Tied Ridges (TR)
4. Flat Land (control) (FL)

Each treatment was applied in plots measuring 4m × 3m (12m^2) and standard spacing for maize planting was maintained.

3.3 Agronomic practices

The field work was carried out following an agricultural practice to facilitate successful crop establishment and management. Land was cleared and pegged according to the experimental design to enable effective planting. Glyphosate herbicide was sprayed as a pre-emergence herbicide to control weeds in the field prior to planting. Soil moisture conservation methods were adopted to conserve soil moisture and facilitate maize growth. Potholing, consisting of digging holes of depth 20-30 cm and spacing of 50 cm across the experimental plots were made. Ridges of dimensions 4m×0.55m×0.30 m (L× W× H) were made at 50 cm between planting rows and tied ridges made by planting similar to ridges but cross ties of 0.8 m made to improve water conservation. Maize seeds were planted on January 3, 2025, following 0.75 m between rows and 0.2 m row spacing. Compound D fertilizer (7: 14:7) was applied at 200 kg/ha as basal fertilizer at planting. Top dressing was done when maize reached knee height using calcium ammonium nitrate (CAN, 27% N) at 120 kg/ha as a way of promoting healthy growth and high yield potential. Manual weeding was carried out whenever the need arose to control weeds and to promote plant growth. Pest control measures for the field was against fall armyworm that attacks the maize. Emamectin was applied at the first sign of infestation to prevent loss of the crop. Agronomic practice were carried out to enhance maximum yield while conserving soil moisture under the prevailing conditions.

3.4 Data collection and measurements

Data was collected to ascertain how different soil conservation methods affect soil moisture retention, maize growth and yield parameters. The data was collected at set intervals to enhance data quality. Some quality control measures were carried out to reduce errors during data collection. Randomization and replication was used to reduce experimental error. Calibration of the measuring tapes and weighing scale was carried out. Uniform soil depths were used in the entire treatments.

3.4.1 Soil moisture content

Soil moisture was collected at two soil depths i.e. 0-15 cm and 15-30 cm depth. Soil was collected from each experimental plot and put in labeled moisture proof containers. Oven method was used to determine the moisture content. Soil samples were weighed to obtain fresh weight. The samples were then oven dried to a constant weight. The dried samples were then weighed to obtain dry weight. Moisture content was calculated as follows;

$$Soil\ moisture\ content\ (\%) = \frac{Initial\ weight - Dry\ weight}{Dry\ weight} \times 100$$

This method ensured precise determination of soil moisture levels, allowing for an accurate assessment of the water retention capacity of each soil moisture conservation technique.

3.4.2 Growth parameters

Maize growth parameters were recorded at week 3, 6 and 9 intervals to monitor the effect of various moisture conservation techniques. A string was wrapped around the base of the maize stem and the length of the string was measured using a ruler to determine stem girth. On plant height, a soft tape measure from the base of the plant to the highest leaf tip was used. These measurements provided insights into how soil moisture availability influenced maize growth changes over a period of time.

3.4.3 Yield measurements

Yield measurements were taken at crop maturity to assess the effect of soil moisture retention techniques on maize productivity. Harvested maize was dried to a 12.5% moisture content through sun drying method. The final yield was expressed in tonnes per hectare (toness/ha) to facilitate comparisons among treatments. 1000 seed weight was also performed.

3.4.4 Experimental model

$Y_{ij} = \mu + T_i + ß_j + e_{ij}$

Where:

Y_{ij} is the observed value of the response variable for the ith treatment in the jth block.

μ is the overall mean of the response variable.

T_i is the effect of the ith treatment (i=1 to 4; Tied ridges, Ridges, Potholing, Flat land).

$ß_j$ is the effect of the jth block (j= 1 to 3; to account for variation among the three replications).

e_{ij} is the random error associated with the ijth observation.

3.4.5 Statistical analysis

Data analysis was performed using Genstat 17th generation statistical software. The effects of different soil moisture conservation techniques on maize growth and yield were analyzed using Analysis of Variance (ANOVA) at a significance level of $p \leq 0.05$. When significant differences among treatment means were detected, Fisher's Least Significance Difference (LSD) test was used to separate means and determine which treatments had statistically different effects on soil moisture retention, maize growth and yield.

CHAPTER FOUR: RESULTS

4.1 Moisture conservation techniques on soil moisture content.

There were statistically significant differences ($p<0.05$) on means of soil moisture content from different moisture retention methods at different weeks. At Week 3, tied ridges (TR) recorded the highest soil moisture, followed by potholing (PH), ridges (RD) and flat land (FL) with the lowest. This trend generally persisted across the weeks, although moisture levels declined over time. At Week 6 and Week 9, TR consistently maintained higher moisture compared to other methods, while FL remained the lowest. (Fig 4.1)

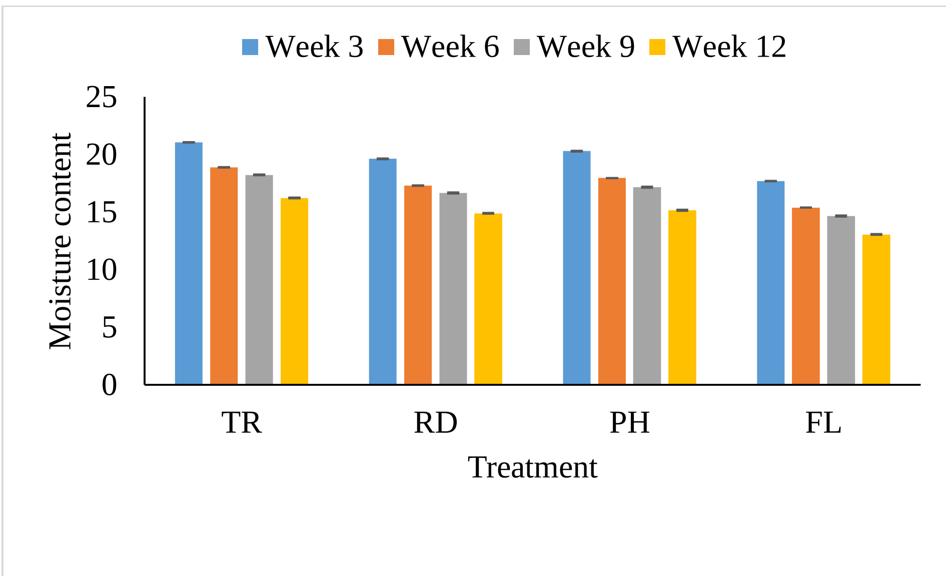

Figure 4.1: Moisture retention methods on soil moisture content.

4.2 Moisture conservation techniques on stem girth.

There were statistically significant differences ($p<0.05$) on maize stem girth means from different moisture retention techniques at different weeks. The graph shows that tied ridges (TR) consistently resulted in the highest maize stem girth across all weeks, indicating better plant growth. (Fig 4.2)

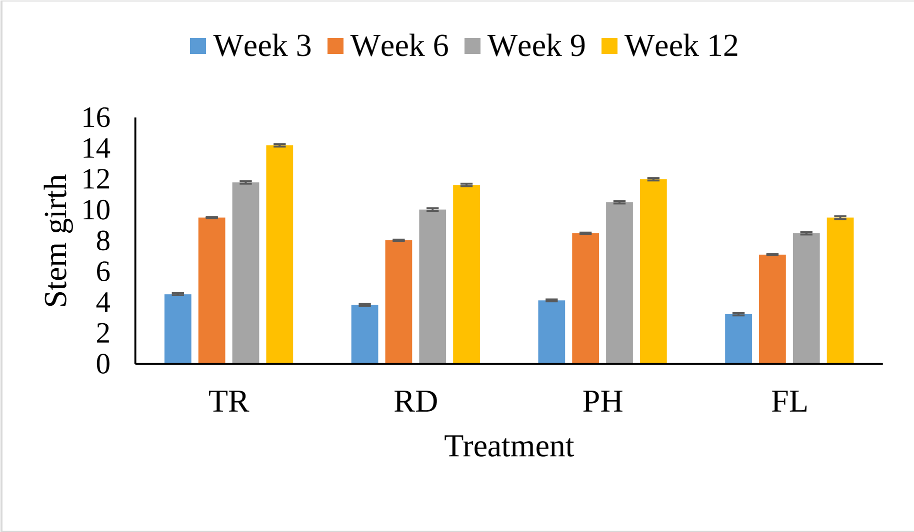

Figure 4.2: Moisture retention techniques on stem girth.

4.3 Moisture retention techniques on maize plant height.

There were statistically significant differences (p<0.05) on plant height means from different moisture retention methods. The graph shows that maize plant height varied across the four treatments (TR, RD, PH, FL) over time. At each measurement week (3, 6, 9, and 12), plants grown on tied ridges (TR) consistently achieved the greatest height compared to the other methods. (Fig 4.3)

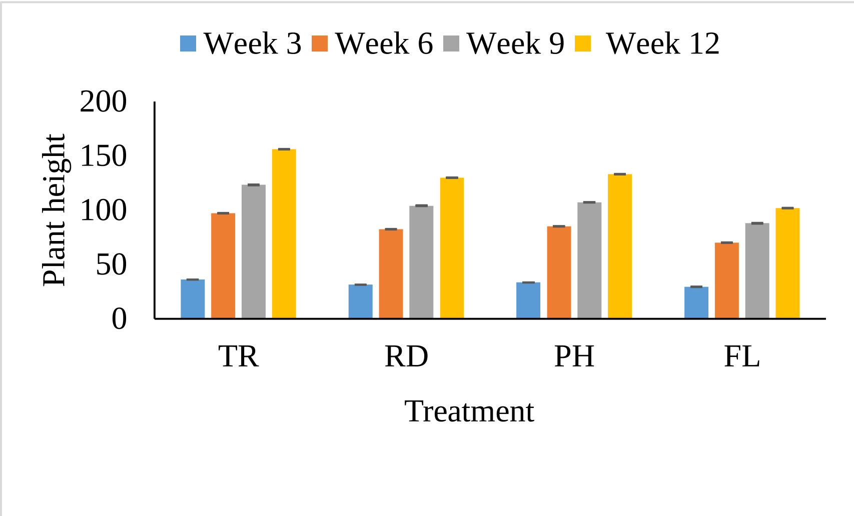

Figure 4.3: Moisture retention methods on maize plant height.

4.4 Moisture retention methods on 1000 seed weight.

The 1000 seed weight means from different moisture retention methods at various weeks showed highly significant differences ($p<0.05$).1000 seed weight of maize at different moisture retention methods indicated that tied ridges (TR) was highest in terms of seed weight, then potholing (PH) and ridges (RD), while the least seed weight was on flat land (FL). (Fig 4.4)

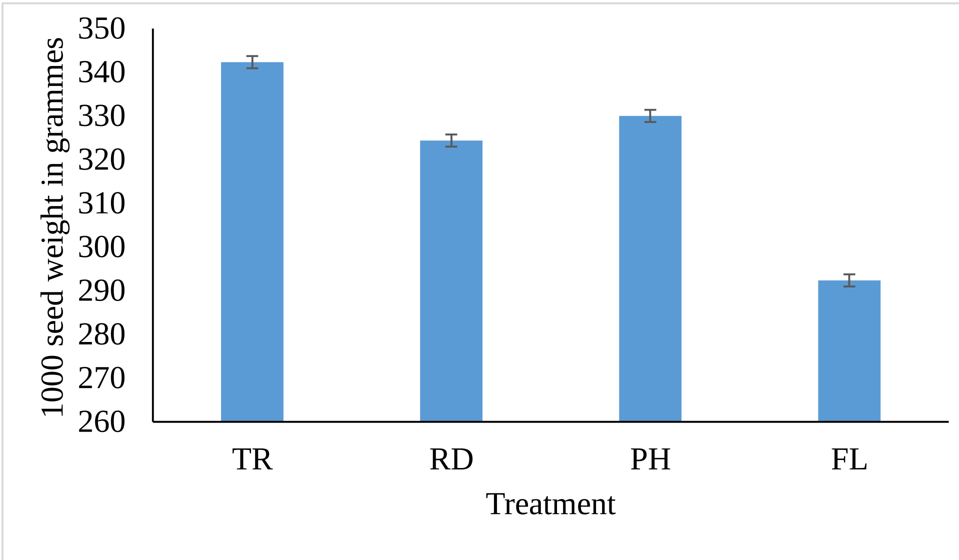

Figure 4.4: Moisture retention methods on 1000 seed weight.

4.5 Moisture conservation techniques on final grain yield.

There were highly significant ($p<0.05$) differences in maize yield means of various moisture retention methods in weeks 3 and 5. The results are depicted in Figure 4.5 below. As observed, tied ridges (TR) recorded the highest maize grain yield, followed by ridges (RD), potholing (PH), and flat land (FL).

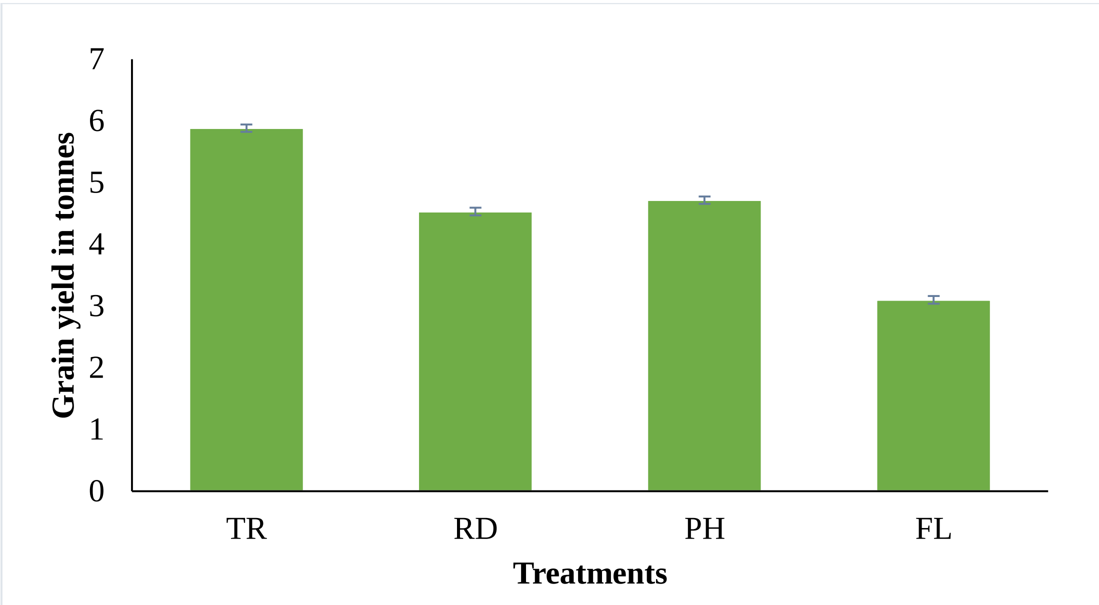

Figure 4.5: Moisture retention methods on final grain yield.

CHAPTER FIVE: DISCUSSION

The present study revealed statistically significant differences ($p < 0.05$) in soil moisture content among the four moisture retention techniques (tied ridges, potholing, ridges and flat land) over time, confirming the effectiveness of soil and water conservation strategies in modifying soil moisture dynamics under semi- arid conditions. However, the soil moisture decreased with time during the cropping period in all treatments. The magnitude of decrease differed among the methods. Tied ridges (TR) consistently recorded higher soil moisture content at weeks 3, 6, 9 and 12 compared to other treatments. This trend is similar to previous studies where tied ridges have been shown to reduce runoff and improve infiltration by creating micro-basins that retain rainwater longer in the root zone (Makoni *et al.,* 2021; Ncube *et al.,* 2022). Spatial differences were evident between treatments with TR outperforming flat land (FL) which showed the lowest moisture retention. This highlights how micro-topographic alterations affect spatial distribution and conservation of soil moisture even within smallholder plots (Chikobvu & Mupfiga, 2023). The superior performance of tied ridges can be observed through their ability to disrupt surface water flow, slow down runoff and increase infiltration time. This is crucial in agro-ecological zone IV where erratic rainfall and rapid surface runoff impede soil moisture retention. The effectiveness of potholing (PH) and ridges (RD) was intermediate implying partial retention benefits but not as much as TR. These findings affirm earlier reports that tied ridging is a suitable moisture conservation technique in semi-arid areas particularly under rain-fed systems. (Mpala *et al.,* 2020). Flat land cultivation left soil exposed to direct solar radiation, leading to lower moisture levels. The study aligns with crop physiology principles where root water uptake efficiency and stomatal conductance are strongly linked to soil water availability in the rhizosphere (Bai *et al.,* 2021). The observed consistency across sampling weeks and treatments allow the generalisation that tied ridging is a reliable soil moisture conservation technique for maize production in semi-arid environments like Ward 33, Zaka District. Given the relatively low variability in TR treatments, we can infer its predictable performance under similar climatic and soil conditions. However, caution should be exercised when generalising results outside the study without further multi-season or multi-location validation. Variability in rainfall intensity, slope gradient and soil texture could influence the efficacy of each method. Even though tied ridges performed better than other methods on average, there were some overlaps in moisture content between tied ridges and potholing (PH) in certain weeks, especially in Week 1. This could be caused by a localised rainfall event or small scale heterogeneity in slope gradients. These minor deviations highlight the need to consider local environmental conditions in research results. The high soil moisture retention capacity of tied ridges can be attributed to water redistribution into small depressions to improve infiltration and reduce surface evaporation. The poor performance of flat land is because water can move rapidly through surface runoffs and evaporate. Ndhlovu *et al.* (2022) argued that tied ridges increase plant water availability through extended water residence time in the root zone. Such residence time enables optimal physiological processes, such as root elongation and turgor, for crop growth and development. The decline in moisture content over time could be due to increased evapotranspiration and maize growth stage. For example, during reproductive stages when evapotranspiration increases and maize demands more water (FAO, 2021). Evapotranspiration can account for more than 60% of soil water depletion in rain-fed maize under dry land conditions during the tasseling and grain filling stages (FAO, 2021).

The results also revealed a significant difference ($p < 0.05$) between moisture retention methods in terms of stem girth at different weeks. At Week 3, the stem girth was relatively low and nearly similar in all moisture retention methods, which showed no much difference in initial growth. From Week 6, however, tied ridges (TR) produced significantly higher stem girth and maintained the higher girth in comparison to other moisture retention methods until Week 12. The continued increase in stem girth of TR demonstrates that moisture retention methods have significant impact on soil moisture availability and it promoted plant stem growth. Spatial variation was also observed in different moisture retention methods, where TR had higher stem girth than the other moisture retention methods. However, planting holes (PH) had lower stem girth in comparison to the other moisture retention methods. Thus, moisture retention method has an impact on stem girth within the same moisture availability conditions. The superior performance of TR can be attributed to its design which improves water infiltration and reduces surface runoff hence increasing soil moisture retention. This is supported by Motsi *et al.* (2004) who reported that tied ridges enhanced soil moisture content and promoted crop growth and yield in Zimbabwe. A study conducted in the Ruzizi watershed found that tied ridges enhanced the stem diameter and leaf area index of maize in comparison to conventional tillage which further support the notion that moisture retention can improve plant growth. Furthermore, tied ridges have also been shown to increase water use efficiency (WUE) of maize crops. Xiao-long *et al.* (2022) discovered that tied ridges increased maize WUE by up to 77.4% compared to conventional flat cultivation under different rainfall levels. This improvement in WUE is important for improving maize growth parameters including stem girth especially in semi-arid regions. Tied ridging can be generalised to be a moisture retention method that improves stem girth in semi-arid areas due to its consistency throughout the growth stages. Moisture retention methods are more important in areas such as Zaka, where moisture stress can reduce crop productivity. Tied ridges generally increase stem girth but may cause waterlogging in fine-textured soils under high rainfall, leading to root hypoxia and reduced growth. Wiyo *et al.* (2000) noted that in normal or wet years, tied ridging could lead to waterlogging in fine-textured soils, highlighting the need to match this technique with local rainfall patterns and soil drainage capacity. The increased stem girth under tied ridging can be linked to the increase in soil moisture availability. Soil moisture availability promotes cell expansion and division in the stem tissues. The availability of moisture improves nutrient uptake and photosynthesis, resulting in an increased biomass accumulation. This physiological mechanism explains the impact of moisture retention on plant growth. Apart from that, the improved microenvironment in tied ridges can also lead to improved soil structure and aeration, thereby increasing root growth and nutrient absorption. These combined factors contribute to the observed increase in stem girth.

In terms of the impact of moisture retention on maize plant height, a significant difference was noted in plant height among the four treatments with tied ridges (TR) having the highest plant height at each sampling point (weeks 3, 6, 9 and 12). As days progressed, the variation in plant height became clearer among the four treatments, as shown in Fig. 4.3. This implies that tied ridging improved plant growth condition at the cost of moisture retention, indicating increased availability of moisture to the plants. On the other hand, maize grown on flat land had the lowest plant height, which means there was insufficient moisture for good physiological function, leading to poor plant growth. This is a clear indication that moisture retention methods play an important role in improving plant height as in the case of tie ridging method (TR) being a dominant moisture retention method compared to the other methods. Although plant height disparity existed within each treatment, this was only limited to the individual plots. The distance between the plots did not vary, proving that plant height variations existed within a given region. Plant height difference was recorded despite the area being part of Agro-ecological Zone IV. This indicated that moisture retention methods were more influential in determining plant height than the prevailing regional weather. Similar observations were noted by Massawe *et al.* (2023) who recorded that tied ridging significantly improved maize plant growth by providing enough moisture to maize grown under semi-arid environment in Tanzania. Moreover, consistent findings were also recorded by Teklehaimanot and Gebregergs (2024) who observed that tied ridging method was superior to the other methods, yielding high maize biomass and plant height in a semi-arid region of Ethiopia (Teklehaimanot & Gebregergs, 2024). The high maize plant height in the tied ridge (TR) plots was due to the ability of the technique to retain and conserve soil moisture in the immediate root zone. As such, the soil surrounding the root zone can hold enough moisture for a longer time which facilitates longer vegetative stage that triggers vegetative growth. Maize requires adequate soil moisture for its metabolic processes such as cell turgor, nutrient uptake and root activity. Performance of ridge and potholing (RD and PH) was intermediate but their performance also supports the research finding. They partly retain moisture compared to tied ridging (TR). Both ridge and potholing methods do not retain moisture to a level comparable to tied ridging (TR) technique.

These observations were also validated by Alemu (2025) who concluded that tied ridging resulted in increased plant height and maize yield through increasing water retention and efficient nutrient utilization (Alemu, 2025). Also, Ndlangamandla *et al.* (2021) reported increased maize plant height and vigor with tie ridging in Swaziland (Ndlangamandla *et al.*, 2021). Hence, it can be generalised that tie ridging method of moisture retention is the most reliable moisture retention method for improving maize plant height in semi-arid environment. The low. The low variation within each treatment in terms of plant height proves that the effect of the treatment is constant and hence strong. TR treatment is therefore a reliable moisture retention method that improve maize plant height in semi-arid environment. The need for tied ridging as a moisture retention method under semi-arid environment can also be generalised to other areas within Agro-ecological Zone IV in Zaka district, considering that the TR technique was superior to the other methods in improving maize plant height in Zaka district. Due to the existence of other parts within Agro-ecological Zone IV in the Zaka district, the use of tie ridging as a moisture retention method should be generalised to other parts within the Agro-ecological Zone IV. Moreover, based on the high plant height observed in the tied ridging (TR) treatment, tie ridging is a reliable moisture retention method for enhancing maize plant height in semi-arid environment. Tied ridging (TR) can be generalised to other areas with similar agro-climatic zones where loamy and sandy-loam soils exist. This is because other soil types might make the structure unachievable in a given soil texture and hence the performance of the method cannot be guaranteed. Furthermore, tied ridging should not be generalisable to clay soils due to the tight nature of the soils. With the absence of soil loosening or proper tillage operations in such soil type, the process of water penetration into the soils will be impeded hence leading to uneven water distribution which might affect plant height negatively. Tied ridging can be applied beyond small-scale farming but its effectiveness on maize height in semi-arid areas depends on soil conditions. In compacted soils, proper tillage is ideal for tied ridging to be beneficial. Tolossa (2025) found reduced effectiveness in poorly drained vertisols due to moisture accumulation. However, when tied ridging is applied appropriately it enhances maize height by improving soil moisture which supports nutrient availability and uptake (Silungwe *et al.,* 2019). Moreover, water is also a requirement for hydrostatic pressure needed for cell elongation and as such, moisture determines plant height. Low plant height in flat land (FL) was due to excessive run-off and poor water retention hence resulting in short-term moisture shortage and poor plant metabolic function. In the absence of sufficient moisture, photosynthesis slows down, turgor pressure reduces and cell elongation does not occur leading to short plants. This was also validated by Silungwe *et al.* (2019) who asserted that moisture retention methods determine maize plant height and biomass under water-limited environments. The finding that tied ridging (TR) was a dominant moisture retention method in terms of maize plant height also suggests that the research findings can be validated by other researchers. This is because they can replicate the experiments carried out in other places to validate the findings of the current study. Tied ridging was found to be the dominant moisture retention method in improving maize plant height under semi-arid environment.

The results indicated statistically significant difference ($p<0.05$) in 1000 seed weight of maize among various moisture retention techniques over time. There was a consistent increase in the 1000 seed weight for the tied ridge plots compared to potholing (PH), ridge (RD) and flat land (FL). Overall, tied ridges promoted progressive seed development as indicated by the increased seed weight as the season progressed. In spatial analysis, tied ridges had significantly higher 1000 seed weight across all replicates and slope positions compared to potholing and ridges. However, the flat land plots had significantly lower seed weight than tied ridges and potholing and lower than tied ridges in ridges. This spatial difference indicates that water retention structures play a key role in enhancing maize productivity in water limited agro ecosystems such as those found in semi-arid regions. Higher 1000 seed weight in tied ridges can be attributed to the enhanced soil moisture retention, which promotes grain filling and carbohydrate translocation. Sufficient moisture during grain filling ensures sustained photosynthetic activity, allowing optimal carbohydrate translocation to the developing kernels. Similar findings have been documented by Ayala *et al.* (2023) that tied ridges resulted in significantly higher seed weight compared to other moisture retention methods due to higher water availability during the critical reproductive stages of maize development [https://www.sciencepublishinggroup.com/article/10.11648/10078151]. Agronomic studies such as that by Guta *et al.* (2021) indicate that maize yield is affected by the water deficit during grain filling. Grain filling stages were found to be a vulnerable stage to water stress and that it caused decreased kernel size and density. While potholing and ridges showed satisfactory performance, they did not have the enclose soil surface micro-catchment capacity that prolongs water infiltration and water retention as tied ridges. The flat land did not have the soil structural modifications that enable water retention which results in high runoff losses, lower soil moisture levels and poor seed development. This further validates the role of moisture availability in supporting physiological mechanisms that regulate seed formation and filling. Given these findings, it can be generalised that tied ridging is the best moisture retention method in the semi-arid environment as indicated by the low variation in the 1000 seed weight across replicates and blocks.

Despite the overall superiority of tied ridges, some replicates showed less 1000 seed weight compared to others within moisture retention methods. This can be attributed to the differences in microclimatic variables, soil texture, or pest/disease outbreaks. The high clay contents of the soils under tied ridging may cause temporary water logging, which compromises root respiration and nutrient uptake that might suppress grain development. On the other hand, even under the tied ridges, minimal rains for consecutive weeks may not result in optimum moisture retention during the growing season. This shows the limitations of tied ridges under extreme drought conditions. The need to incorporate additional measures such as mulching or drought-tolerant varieties to enhance tied ridges is demonstrated. Tied ridges could therefore be integrated with other agronomic practices to increase their effectiveness under different agro-ecological zones. The high 1000 seed weight under tied ridges is as a result of interactions between physiological and environmental mechanisms. Moisture availability during grain filling stage is vital because it influences the plant demand for assimilates. It is well established that drought stress during this stage reduces starch deposition in endosperm and decreases kernel weight (Taiz *et al.,* 2023). Tied ridges minimize water loss through reducing runoff and increasing infiltration which promotes consistent photosynthate supply and efficient translocation to the cob leading to heavier seed weight. Similar findings have been reported by Tolossa (2025) that tied ridges significantly improved the yield components of maize grown in the dry-lands of Ethiopia [https://onlinelibrary.wiley.com/doi/full/10.1155/aia/7626458]. Tied ridges have an added advantage of moderating root zone temperature and avoiding water stress induced stomatal closure to sustain photosynthesis and kernel development.

The current study adds to the existing evidence for moisture retention practices in dry-land agriculture. It provides empirical evidence for the use of tied ridges to enhance one of the yield components under rain-fed maize production—seed weight. Most previous studies have been focusing on yield per hectare without considering other quality indicators of productivity. This study identifies seed weight as an important quality indicator that can be improved through moisture management practices. This information will inform agricultural extension programs promoting climate smart practices among smallholder farmers. The study will also add evidence from the Zimbabwean agro-ecological zone IV region that has not yet been documented.

There was a significant difference in maize grain yield among the moisture retention techniques. There was an increase in yield among tied ridge (TR) treatments compared to the ridge (RD), potholing (PH) and flat land (FL) across all the study sites. This indicates that TR is the best method in enhancing maize yield. These results agree with findings from the earlier study in the semi-arid regions of Ethiopia and Zimbabwe, which showed that TR increased maize yield by 20-60% over traditional practices (Ajwang' *et al.*, 2018; Shimoni *et al.*, 2019). The spatial variation of the TR treatment also showed a better performance in the different study sites. This implies that TR works in any study site and can be applied as a moisture conservation practice. The consistency in maize grain yield performance between study sites indicates that TR is reliable in enhancing moisture conservation. The consistent improvement in maize grain yield among the moisture retention methods could be due to TR conservation of soil moisture. TR retards water run-off and increases soil water infiltration thereby maintaining more soil moisture which are the major requirement for maize growth, especially during the critical growth stage during dry spells. Several studies have proved that the tied ridge has improved soil water storage and maize yield in the moisture stressed environment (Manz *et al.*, 2017; Hojjati *et al.*, 2017; Ajwang' *et al.*, 2018).

Conversely, the flat land (FL) methods have no structural modifications to conserve soil moisture and have high run-off and low soil moisture content hence low maize yield (McGrath and McGinnity, 2006; Tronvoll and Slabaugh, 2014). Therefore, this study can conclude that there is a generalisation of increasing maize grain yield when moisture retention method of tied ridge is applied as moisture conservation method in semi-arid areas. It is evident that there is consistent improvement in maize grain yield across different locations and seasons in all the sites. This indicates that TR moisture conservation method is effective and it can be adapted in enhancing maize grain yield in the moisture stressed areas. However, the extent of increase in maize grain yield among the moisture retention methods depends on different soils, rainfall pattern and soil moisture retention management. The micro-environment of tied ridge moisture retention method has supported maize to absorb more nutrients and its physiological process resulting in high maize grain yield. In flat land moisture retention method, there is less retention of soil moisture, thus maize grain yield was reduced due to high water stress during dry spells (McGrath and McGinnity, 2006; Ajwang' *et al.,* 2018). This indicates that moisture retention method is the best moisture conservation method that should be adopted to enhance maize grain yield in moisture stressed areas. This study adds to the previous studies that prove the role of tied ridge moisture retention method in enhancing maize grain yield in the moisture stressed areas. By showing the significance of the increase in maize grain yield in moisture retention methods of tied ridge, this study has given information that farmers, extension agents and policy makers will apply tied ridge moisture retention method in enhancing maize grain yield under climate change. This study also recommends that moisture retention method should be adopted depending on the environment and available resources. The moisture retention method should be applied in areas where there are moisture constraints. The next step of this study will focus on integrating moisture retention method with other sustainable agricultural practices in enhancing maize grain yield.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

TR (tied ridging) outperformed RD (ridges), PH (potholing) and FL (flat land) for all parameters. TR maintained the most soil moisture, the largest stem girth and plant height, largest 1000-kernel weight and the highest grain yield (~50 % more than FL). This is due to micro-basins which slow runoff and prolong water availability during the growth period. It works well in the semi-arid environment of Zaka District but could be ineffective on poorly drained clay soils and in very wet seasons, and high labour input may deter adoption.

6.2 Recommendations

Farmers in semi-arid areas are encouraged to adopt tied ridges for maize production. This method offers a cost-effective way to enhance water-use efficiency under increasing drought and rainfall variability. However, further multi-seasonal research is recommended to assess the long-term effects on maize growth, yield components and soil health. Future studies should also consider labor requirements, economic viability and how these methods interact with fertilizer and pest control strategies. These findings will support the development of climate-smart farming practices for smallholder farmers in agro-ecological region IV.

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APPENDICES

Appendix 1

Week 3 soil moisture content

Variate: Soil_moisture_content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.285000	0.142500	102.60	
Block.*Units* stratum					
Treatment	3	18.689167	6.229722	4485.40	<.001
Residual	6	0.008333	0.001389		
Total	11	18.982500			

Appendix 2

Week 6 soil moisture content

Variate: Soil_moisture_content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.2816667	0.1408333	169.00	
Block.*Units* stratum					
Treatment	3	19.7425000	6.5808333	7897.00	<.001
Residual	6	0.0050000	0.0008333		
Total	11	20.0291667			

Appendix 3

Week 9 soil moisture content

Variate: Soil_moisture_content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.246667	0.123333	37.00	
Block.*Units* stratum					
Treatment	3	20.110000	6.703333	2011.00	<.001
Residual	6	0.020000	0.003333		
Total	11	20.376667			

Appendix 4

Week 12 soil moisture content

Variate: Soil_moisture_content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.281667	0.140833	46.09	
Block.*Units* stratum					
Treatment	3	15.589167	5.196389	1700.64	<.001
Residual	6	0.018333	0.003056		
Total	11	15.889167			

Appendix 5

Week 3 stem girth data

Variate: Stem_girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.021667	0.010833	1.44	
Block.*Units* stratum					
Treatment	3	2.700000	0.900000	120.00	<.001
Residual	6	0.045000	0.007500		
Total	11	2.766667			

Appendix 6

Week 6 stem girth data

Variate: Stem_girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.051667	0.025833	10.33	
Block.*Units* stratum					
Treatment	3	8.970000	2.990000	1196.00	<.001
Residual	6	0.015000	0.002500		
Total	11	9.036667			

Appendix 7

Week 9 stem girth data

Variate: Stem_girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.00167	0.00083	0.08	
Block.*Units* stratum					
Treatment	3	16.70250	5.56750	513.92	<.001
Residual	6	0.06500	0.01083		
Total	11	16.76917			

Appendix 8

Week 12 stem girth data

Variate: Stem_girth

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.00167	0.00083	0.08	
Block.*Units* stratum					
Treatment	3	33.34000	11.11333	1025.85	<.001
Residual	6	0.06500	0.01083		
Total	11	33.40667			

Appendix 9

Week 3 plant height

Variate: Plant_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.14607	0.07303	1.56	
Block.*Units* stratum					
Treatment	3	73.75693	24.58564	525.21	<.001
Residual	6	0.28087	0.04681		
Total	11	74.18387			

Appendix 10

Week 6 plant height

Variate: Plant_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.3400	0.6700	4.82	
Block.*Units* stratum					
Treatment	3	1119.5067	373.1689	2686.82	<.001
Residual	6	0.8333	0.1389		
Total	11	1121.6800			

Appendix 11

Week 9 plant height

Variate: Plant_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.9817	0.4908	1.88	
Block.*Units* stratum					
Treatment	3	1880.9700	626.9900	2403.80	<.001
Residual	6	1.5650	0.2608		
Total	11	1883.5167			

Appendix 12

Week 12 plant height

Variate: Plant_height

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.6650	0.3325	2.51	
Block.*Units* stratum					
Treatment	3	4438.8825	1479.6275	11167.00	<.001
Residual	6	0.7950	0.1325		
Total	11	4440.3425			

Appendix 13

1000 seed weight

Variate: %1000_seed_weight_grammes

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	48.500	24.250	8.31	
Block.*Units* stratum					
Treatment	3	4088.250	1362.750	467.23	<.001
Residual	6	17.500	2.917		
Total	11	4154.250			

Apendix 14

Grain yield

Variate: Yield_tonnes_ha

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.071667	0.035833	6.45	
Block.*Units* stratum					
Treatment	3	11.724167	3.908056	703.45	<.001
Residual	6	0.033333	0.005556		
Total	11	11.829167			