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Resilience and economic benefits of climate smartagriculture practices in semi-arid Tanzania

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RESILIENCE AND ECONOMIC BENEFITS OF CLIMATE SMART AGRICULTURE PRACTICES IN SEMI-ARID TANZANIA

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A Dissertation Submitted in Partial Fulfilment of the Requirements for the Degree of Master's in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

The shift of growing seasons onset due to rainfall and seasonal variability are among the climate change impacts affecting agricultural productivity in semi-arid. Seasonal variations in planting dates in semi-arid Tanzania because of climate variability and change make difficulties among farmers in determining the appropriate planting dates. Climate-smart agriculture (CSA) practices are reinforced to mitigate such climate change impacts and sustain crop production, though there is limited information on the performance of CSA practices under the uncertainty of planting dates due to unpredictable rainfall on-set and patterns. This study assessed the effects of CSA practices, planting dates and interaction on soil moisture, maize growth and yield and their economic benefits at Mlali village of Dodoma, Tanzania. A split-plot experimental design was adopted, treatments involved four CSA practices and three planting dates. Maize plant height, leaf area index and biomass were measured during growth while grain, nutrient uptake and economics monitored at harvest. In both seasons, *chololo* pits and tied ridges CSA practices demonstrated the highest soil moisture at 10.8% and 13% that influenced maize growth and yield. *Chololo* pits at early and tied-ridges at late planting dates significantly ($p = 0.047$ and $p = 0.001$) increased grain yield respectively in both seasons. In 2017/2018, tied ridges at normal planting dates had higher marginal net return of 910 USD ha^{-1} and 697 USD ha^{-1} similarly in 2018/2019, tied ridges at late (315 USD ha^{-1}) and *chololo* pits at early planting (434 USD ha^{-1}). These results recommend *chololo* pits at early and tied ridges at late planting dates as appropriate CSA practices for resilience and economic benefits among smallholder farmers in semi-arid Tanzania.

DECLARATION

I, Abiud Missana Gamba do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology that this dissertation is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

.... 11·06·2020 ....

Mr. Abiud Missana Gamba **Date**

Name and signature of a candidate

The above declaration is confirmed

.... 11-06·2020 ....

Dr. Kelvin Mark Mtei **Date**

Name and Signature of Supervisor

.... 11·06-2020 ....

Dr. Anthony Anderson Kimaro **Date**

Name and Signature of Supervisor

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CERTIFICATION

The undersigned certify that they have read the dissertation titled "Resilience and Economic Benefits of Climate Smart Agriculture Practices in Semi-arid Tanzania" and recommended for examination in fulfillment of the requirements for the degree of Master's in Life Sciences with specialization in Sustainable Agriculture of the Nelson Mandela African Institution of Science and Technology (NM-AIST).

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DEDICATION

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LIST OF ABBRVIATIONS AND SYMBOLS

%	Percentage
a.s.l.	Above Sea Level
ACE II	African Centre of Excellence phase 2
ANOVA	Analysis of Variance
CREATES	Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability in Food and Nutritional Security
C	Carbon
cm	Centimeter
CGIAR	Consultative Group for International Agricultural Research
CSA	Climate Smart Agriculture
CIAT	International Center for Tropical Agriculture
CV%	Coefficient of Variation
DPP	Directorate Plant Production
FAO	Food and Agriculture Organization
Fig.	Figure
g	Gram
ha	Hectare
ICRAF	International Council for Research in Agroforestry
K	Potassium
Kg	Kilogram
Kg ha^{-1}	Kilogram per hectare
LSD	Least Significant Differences
Lt	Liters
m	Meter
mm	Millimeters
MANRLF	Ministry of Agriculture, Natural Resources, Livestock and Fisheries
N	Nitrogen
NM-AIST	Nelson Mandela African Institution of Science and Technology
P	Phosphorus
p	Probability
RCBD	Randomized Complete Block Design
SSA	Sub - Saharan Africa

t ha^{-1}	Tone Per Hectare
TN	Total Nitrogen
TMA	Tanzania Metrological Agency
USAID	United State Agency for International Development
USDA	United State Department of Agriculture

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Climate variability constrains agricultural productivity of many crops in most sub-Saharan African (SSA) countries including Tanzania (Midega *et al.*, 2015; Thornton *et al.*, 2014; Thornton *et al.*, 2018). Shifting of rainfall patterns due to climate change is the main weather element that constrains soil moisture availability in the soils and contributing to low maize production (Demeke *et al.*, 2011; Omondi *et al.*, 2014). The impacts of climate variability are compounded by farming practices such as intercropping, tied ridges and planting basins or *chololo* pits which are poorly adapted to optimize the use of available water and thus have also contributed to reduced agricultural productivity (Porter *et al.*, 2017; Thornton *et al.*, 2014).

Studies show that 80% of the world's croplands is under rain-fed agriculture whereby food supplies and maize produce in East Africa covers 95% and 60% respectively under the same farming system (FAO., 2014; Woomer *et al.*, 1998). In Tanzania, more than 70% of the population lives in rural areas (Mayaya *et al.*, 2014), and depends on rain fed agriculture for their survival and economic development similar to many smallholder farmers in other SSA countries (Scherr *et al.*, 2012; Thornton *et al.*, 2014; Watkiss *et al.*, 2010). Part of the challenges caused by climate change is unpredictable precipitation patterns, inconsistence of rainfall onsets, insufficient soil moisture, increases in soil temperature and other socio-economic factors (FAO., 2014; Mongi *et al.*, 2010; Msongaleli, 2015). The rise in mean annual temperature coupled with shifting of rainfall onset may reduce maize production by 13% in Tanzania by 2030 (FAO, 2013; MALFs, 2014). These increasingly shifting and unpredictable rainfall patterns not only affect production but also make it difficult for farmers to decide on the appropriate practices and planting time (Kimaro *et al.*, 2016; Nyagumbo *et al.*, 2017). Consequently, various farming systems such as conservation agriculture, cereal-legume intercropping, agroforestry, use of disease and drought tolerant crop varieties and integrated soil fertility management practices have been considered as climate-smart agriculture practices (Rosenstock *et al.*, 2016; Thierfelder *et al.*, 2013). However, the resilience of these CSA practices under climate variability associated with inappropriate planting dates due to inconsistent rainfall patterns has been less researched and demonstrated in many semi-arid conditions (Kimaro *et al.*, 2016; Lamanna *et al.*, 2016).

There are unpredictable planting dates among smallholder farmers in Tanzania due to inconsistence of rainfall onsets, insufficient soil moisture, increases in soil temperature and other socio-economic factors (Kangalawe & Lyimo, 2013; Msongaleli, 2015). Such factors have also led to maize crop failure and decline in yields by 5% (Nyagumbo *et al.*, 2017). To mitigate these climate variability and change, several climate-smart agriculture (CSA) practices like tied ridges, *Chololo* pits and intercropping are recommended (Lipper *et al.*, 2014). Such rain water harvesting practices are good mitigation and adaptation measures to sustainably increase agricultural productivity and build resilience under extreme climate (Kizito *et al.*, 2016). Conservation Agriculture (CA) has been recognized as the best fit CSA practices in most Sub-Saharan African countries due to their resilience to climate change (FAO., 2014; Kangalawe & Lyimo, 2013; Neufeldt *et al.*, 2013). Adoption of CSA practices and appropriate planting dates to address effects of climate change and variability is a promising option to mitigate the climatic extremes and to build agroecosystem resilience among smallholder farmers (Niang *et al.*, 2017).

Using climate resilient CSA practices and better management of the current climate variability may enhance farmer adaptation to the increasing threats of climate change (Kimaro *et al.*, 2016; Mupangwa *et al.*, 2017). Potential adaptation options that would help to build resilience of maize production systems include better access and use of weather information coupled with the use of climate resilient technologies of appropriate CSA practices (Kimaro *et al.*, 2019; Lamanna *et al.*, 2016). Conservation Agriculture as a CSA practice increased water and nutrient use efficiency that lead to higher yields and economic benefits (Campbell, 2011). Reduced input costs by more than 40% were achieved by farmers practiced CSA practices like *chololo* pits and intercropping while crop yield increased at 6% (LI *et al.*, 2011; Ndakidemi *et al.*, 2006; Thornton *et al.*, 2018). The agro ecological approaches under CSA practices links the social and environment that account of potential cost benefits of these CSA practices. The uncertainty of margin costs over climate variability is higher, calls for cost benefit analysis of the resilience agricultural practices to thrive under such climate change (Campbell, 2016; Thornton *et al.*, 2018). Therefore, in this study, selected CSA practices and planting dates were assessed in the farming systems of semi-arid central Tanzania to address climate variability and change to propose useful practices in the existing knowledge that can be adopted by smallholder farmers in their local settings.

1.2 Statement of the problem

The occurrence of extreme climatic events and unpredictable rainfall patterns are increasingly threatening economic growth and development in Tanzania. Climatic extremes are projected to cost the country a loss in GDP of about 1–2%, with severe consequences on the livelihoods of its population (UNEP, 2009; Watkiss *et al.*, 2011). Agriculture sector is prone to such climatic extremes as 80% decline in yields is expected due to unreliable rains and prolonged droughts (Ehrhart & Twena, 2006). Kongwa district is among the semi-arid areas in Tanzania vulnerable to these climate extremes as currently it experiences decline in crop productivity (Mayaya *et al.*, 2014; Mongi *et al.*, 2010; Msongaleli, 2015). Those extremes are due to short and unpredictable rainfall patterns with an average of 570 mm annual rainfall (Mayaya *et al.*, 2014). These increasingly shifting and unpredictable rainfall patterns not only affect production but also make it difficult for farmers to decide on the appropriate CSA practices and planting time. There is need to address the problem of low yield and cost implications among smallholder farmers due to inappropriate farming practices and planting dates which are highly aggravated by climate variability and change.

1.3 Rationale of the study

A better understanding of the resilient adaptation and mitigation strategies such as CSA practices required to improve soil moisture and crop production is highly needed. Furthermore, there is limited information and knowledge among smallholder farmers and actors on appropriate planting dates coupled with improved farming practices for optimal and beneficial resilient crop production in semi-arid areas. In this context, a study to assess the resilient effects and economic benefits of Climate Smart Agriculture practices in Semi-arid areas Tanzania was designed and conducted during the 2017/2018 and 2018/2019 cropping seasons at Mlali village of Kongwa District.

1.4 Objectives

1.4.1 General objective

The general objective of this study was to assess the resilience and economic benefits of selected CSA practices and planting dates as Climate Smart Agriculture practices in Semi-arid areas Tanzania.

1.4.2 Specific objectives

(i) To assess soil moisture content dynamics in selected CSA practices at different planting dates.

(ii) To determine the effects of selected CSA practices, planting dates and their combination on growth and yield of maize.

(iii) To evaluate the economic benefits of selected CSA practices, planting dates and their combination.

1.5 Hypothesis

1.5.1 Null hypothesis (Ho)

The selected CSA practices, planting dates and their combination have no effect on soil moisture content, maize yield and economic benefits.

1.5.2 Alternative hypothesis (Ha)

The selected CSA practices, planting dates and their combination have an effect on soil moisture content, maize yield and economic benefits.

1.6 Significance of the study

This study within BCfRFS project, through Capacity 1 implemented by ICRAF, will contribute to address the existing knowledge gap by determining the potential benefits and trade-offs of CSA practices under different local conditions by region and production system. Through strengthening of CSA knowledge base and provide scientific information to underpin wide scaling of CSA practices in Tanzania, this will help to build the capacities of farmers and other stakeholders under Ministry of Agriculture (MoA) in quantifying the benefits and trade-offs of CSA practices compared with conventional practices in terms of agricultural productivity (yield and biomass), costs and benefits, and the resulting adaptation/resilience and mitigation benefits and developed reference and demonstration sites/plots that can be used as field learning laboratories to demonstrate, teach, and communicate to different stakeholders (farmers, researchers, National Agricultural Research Systems, non-government organizations and policy makers) on the benefits of CSA practices.

1.7 Delineation of the study

This study adopted a split-plot experimental with four CSA practices as a main factor and three planting dates as sub-factor replicated three times to assess the effects of CSA practices, planting dates and interaction on soil moisture, maize growth and yield and their economic benefits at Mlali village of Dodoma, Tanzania. In this study treatments involved were CSA practices (*Chololo* pits, tied ridges, intercropping and Ox-cultivation – as a control) and/at planting dates (Early, Normal and Late planting).

CHAPTER TWO

LITERATURE REVIEW

2.1 Climate-Smart agriculture (CSA)

Climate-smart agriculture (CSA) is a concept that reflects the integration of agricultural development and climate responsiveness, with the aim of achieving food security and broader development goals under a changing climate and increasing food demand. Climate-smart agriculture (CSA) is agriculture that sustainably increases productivity and income, ability to adapt and build community resilience to climate change and enhances food and nutrition security while achieving mitigation co-benefit in line with national economic development priorities (Thornton *et al.*, 2018). Climate-smart agriculture (CSA) initiatives focus is to increase productivity, enhance resilience, and minimize greenhouse gas emissions. The overall goal is to address tradeoffs and synergies between the three pillars i.e. productivity, adaptation, and mitigation (Lobell *et al.*, 2008; Mertz *et al.*, 2009; Ramírez & Thornton, 2015). Maize-pigeon pea intercropping can be a good option to deal with climate uncertainty for late planting windows within a cropping season (Liebman & Dyck, 1993). Conservation Agriculture practices of ideal farming practices and planting dates are among the key components and farming operations necessary for the development of CSA practices.

2.2 Principles of conservation agriculture (CA) as CSA Practice

Conservation agriculture (CA) is an approach to managing agro-ecosystems for improved and sustained productivity, increased benefits and food security while preserving and enhancing the resource base and the environment (Derpsch *et al.*, 2010). CA helps to restore soil fertility and it has potential for mitigating and adapting to the impacts of climate change (Shetto & Owenya, 2007). As a CSA practice, CA has potential to increase crop yield and economic returns due to its ability to minimize risks of crop failure in droughts (Hobbs *et al.*, 2008; Mupangwa *et al.*, 2017). Practicing CA principles significantly increase and stabilize crop yields and preserves the natural resources that are critical for food production, especially in areas with low rainfall (ACT, 2008; Marongwe *et al.*, 2011). Yields of maize grown under different CA systems in Southern Africa were reported to be higher than maize yield grown under non-CA at 80% (Rusinamhodzi *et al.*, 2011; Thierfelder *et al.*, 2013). Apart from yielding, CA integrated with leguminous crops like pigeon pea, subsequently combats climate change through emissions by modifying nutrient stocks that affect greenhouse gas fluxes (Kimaro *et al.*, 2009; Liebman & Dyck, 1993).

2.3 Climate-Smart agriculture (CSA) practices in smallholder farmers

Smallholder farmers in East Africa have well adapted to mono cropping, crop rotation, sequential cropping, mixed cropping, inter cropping, tied ridging, planting basins and terracing CSA practices (Gebregergs *et al.*, 2016). The decision on which CSA practices to use is determined by the need for diversification and increased climate variability as the emphasis is to increase soil fertility and soil moisture regimes to sustain or increase crop productivity. A CSA practice can predict the seasonal rainfall at the start of each rainy season, and modifying the CSA practices accordingly (Mupangwa *et al.*, 2017; Thierfelder *et al.*, 2013). Studies by (Tsubo & Walker, 2007) observed that management of CSA practices according to the rainfall pattern improved water and crop productivity in dry land rain-fed systems. The temporal and spatial high climate variability often results to incoherent farmer's decisions on CSA practices due to variation in planting dates from one cropping season to the next and other localized and hard to quantify socio-economic factors (Kimaro *et al.*, 2016).

2.3.1 *Chololo* pits CSA practices

In Sub Sahara Africa, CSA is encompassing a wide range of tillage techniques ranging from non-ploughing and reduced tillage to ripping and sub-soiling (Mupangwa *et al.*, 2017; Shetto & Owenya, 2007). Eastern and Southern Africa countries are commonly using planting basins/*chololo* pits as CSA practices that are well known as soil moisture retention and water harvesting techniques (Biazin *et al.*, 2012). Due to dependence on rain-fed agriculture, *chololo* pits ensure soil moisture availability for plant growth and resilient crop production in semi-arid conditions susceptible to climate change (Nellemann & MacDevette, 2009). CSA/CA practices has shown that reduced soil disturbance and crop residue retention changes to soil physical properties such as hydraulic conductivity and bulk density, can increase water infiltration rates and soil moisture retention helping crops cope with intra-seasonal dry spells (Kimaro *et al.*, 2008; Thierfelder *et al.*, 2013). CSA practices like planting basins regulate soil temperature and precipitation capable to increase production by 6% as compared with 19% decline in yield in prolonged drought or poor precipitations (Ramirez-Villegas & Thornton, 2015). In semiarid areas of Tanzania, 26.2% farmers of Dodoma region are practicing *chololo* pits/planting basins which is a well-known CSA practices (Kahimba *et al.*, 2014). The practice holds runoff and allows retention of extra moisture in pits during crop establishment in semi-arid areas with initial erratic rainfall as their spaces between the pits act as micro-catchments (Mkoga *et al.*, 2010). But still rainfall variability affects maize crop negatively and is predicted to be further declined due to unpredictable rainfall which results into long-term droughts and shortens the growing season (EU, 2014; Nelson *et al.*, 2014). Shifting of rainfall patterns as impact of Climate change will therefore inevitably affect the economy and livelihood of people. Thus, use of *chololo* pits/planting basins as one of the adaptation strategies to cope with such climatic extremes would be a best Climate Smart Agriculture option in terms of resilience crop production and economic benefits among smallholder farmers.

2.3.2 Intercropping as CSA practice

Intercropping of cereal and legumes requires the arrangement of the planting patterns and dates of the companion crops (Lingaraju *et al.*, 2008). Consideration of designs is important to reduce crop resources competition (Liebman & Dyck, 1993). There are fewer risks of crop failure under intercropping in areas with unreliable rainfall as compared with sole cropping (Cooper *et al.*, 2008) as intercropping enhance the productivity of the main crop (Giller, 2001). Grain yield under maize legume intercrops was reported higher (LER ≥ 1), efficient in resource utilization and improved yield of the main crop (Baldé *et al.*, 2011). The crop yield varies with respect to location, radiation, temperature, and water supply conditions, however, PAR is determined by leaf area index (LAI) (Birch *et al.*, 2003; Lizaso *et al.*, 2003). Light competition in intercrop affects the crop performance as shading effect reduce LAI, which consequently reduces the growth performance of the minor crop. Nevertheless, intercropping increase the radiation, maintain higher radiation use efficiency and crop productivity (Keating & Carberry, 1993; Mariscal *et al.*, 2000). Maize-pigeon pea intercropping has found positive significance to maize yield (Sakala, 1994) as it improves the socioeconomic and ecological intensification particularly increase in soil organic carbon (Rusinamhodzi *et al.*, 2011). Such practice economizes the use of nitrogenous fertilizers and increasing the productivity and profitability per unit area and time (Nyoki & Ndakidemi, 2016) leads to improved soil fertility and enhanced ability of the land to capture and store rainfall, creating resilient CSA practices (Sileshi *et al.*, 2011).

2.3.3 Tied ridges as CSA practice

Crop production in semi-arid areas is strongly affected by soil moisture availability during the growth period. Adoption of CSA practices like in-situ water harvesting techniques such as tied ridges are needed to improve water availability for resilient crop productivity (Grum *et al.*, 2017; Kimaro *et al.*, 2019). The study by Grum *et al.* (2017) to test the efficacy of using tied ridges to improve soil water availability for plant growth in Ethiopia revealed that there was a significant (22.4%) increase in average soil moisture content relatively to ox-cultivation (19.9%). The findings suggest that tied ridges enhance water infiltration into the soil and improve water availability during the growing season, thereby protecting crops from dry periods (Wiyo *et al.*, 2000). Tied ridges is one of the CSA practices recommended in semi-arid areas with short rains and prolonged droughts in reducing runoff and improved soil water management for resilient crop growth (Biazin *et al.*, 2012; Jones & Tengberg, 2000; Hobbs, 2007). Tied ridges CSA practice minimizes the loss of water in the soil by evaporation similarly to *chololo* pits or planting basins which has also demonstrated high rain water use efficiency (Stewart & Steiner, 1990).

2.4 Decision on planting dates in smallholder farming systems

Planting dates are important to ensure a favorable climate for critical plant growth as early-planted crops encounter lower soil and air temperatures in early developmental stages (Sacks *et al.*, 2010). The timing for planting is associated with seasonal environmental changes such as sunshine and temperature that affects the growth and development of plants.

The use of weather information in deciding the appropriate planting window in combination with best bet farming practices can play a great role in maize yield optimization (Kirui *et al.*, 2010). It needs a clear understanding and use of weather information trends as an essential tool that provides early warning sign to design adaptation measures such as adjustment to planting dates to cope with unpredictable rainfall patterns (Kirui *et al.*, 2010; Osbahr *et al.*, 2011). The decision for appropriate planting dates among smallholder farmers in most sub-Sahara Africa relies on rainfall distribution patterns. In Tanzania, rainfall information over more than 30 cropping seasons are used to determine planting dates (Daly *et al.*, 2016; Luhunga *et al.*, 2019). However, there are no empirical evidence in terms of extent of contribution to maize production that farmers will gain or lose if they don’t use the TMA weather information on cropping season. Studies by EU (2014) recommend that due to short rain fall season during the third week of November to early January, maize sown in mid-

December would be exposed to less risks of crop failure thus be reasonable early planting date. TMA (2017) recommends the rain onset in mid-December to early January is mostly recognized by farmers in Kongwa as normal planting date however due to shifting in rain onset pattern sometimes it starts much earlier or delayed to the normal range (Fig. 1).

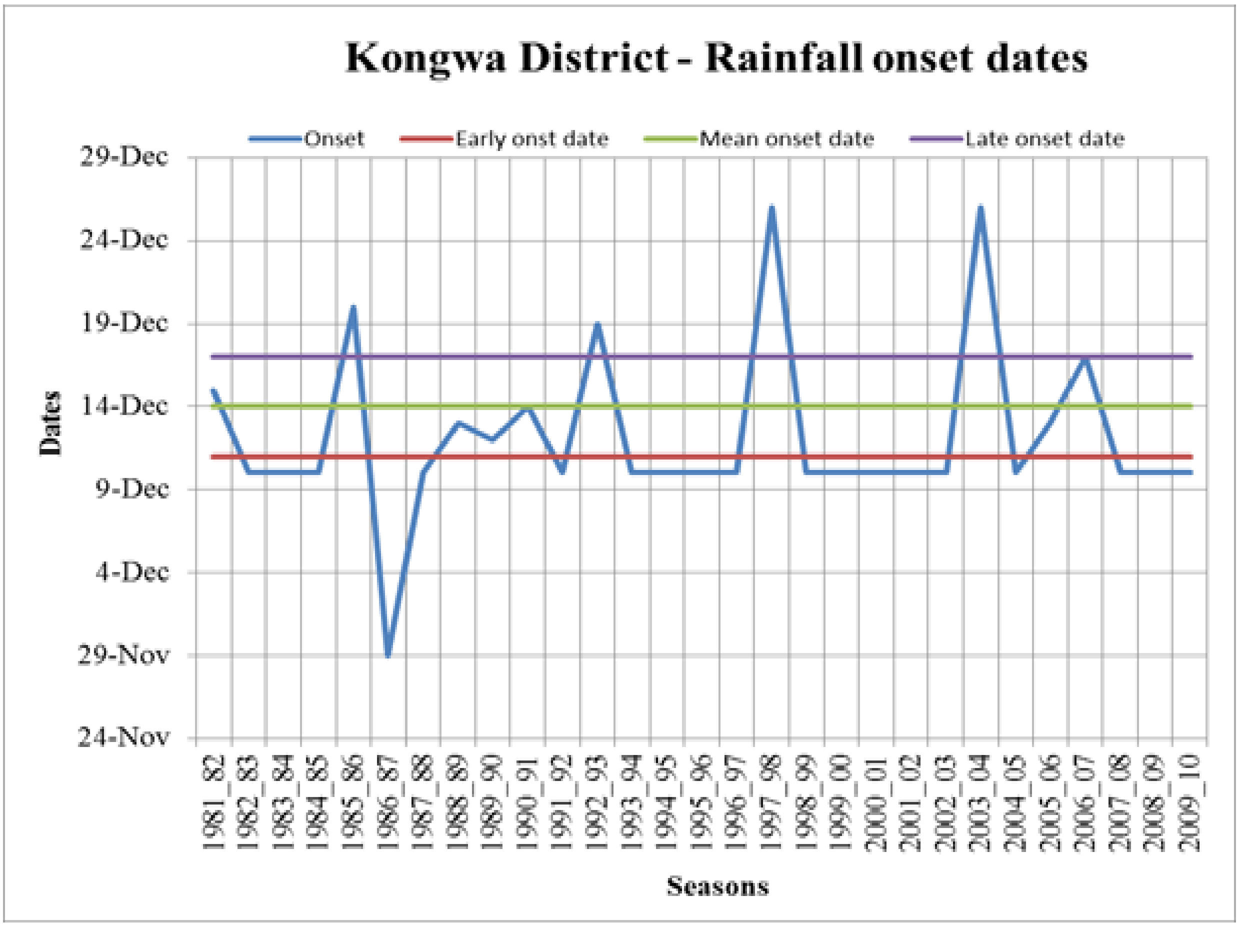

Figure 1: Dates for the beginning (onset) of the short rainfall seasons in Kongwa District from the periods of 1982 to 2010 (TMA, 2017)

2.4.1 Effects of planting dates on soil moisture

The growth of rhizosphere microorganisms is influenced by soil moisture deficit below critical tolerance limits and indirectly by altering plant growth, root architecture and exudations (Badri & Vivanco, 2009). The decrease in soil water results in dried root hair, retard nodule growth and reduced nitrogen fixation in the soil (Hsiao & Xu, 2000). The onset and cessation dates, amount, distribution, duration, and intensity of rainfall help to know the crop response at different planting dates for optimized yield and water productivity of a given CSA practice (Brown, 2015; Cirilo & Andrade, 1994; Cooper *et al.*, 2008; Kurukulasuriya & Rosenthal, 2013). Soil moisture deficit associated with short rains and late planting interfere with photosynthesis to cause reduced crop growth and yield (Pandey *et al.*, 1984; Yordanov *et al.*, 2000). Climatic extremes like drought occur at any time during the growing season (Schneider *et al.*, 1997) which may cause plants to be stressed with water deficit during later stages of reproductive growth or when crops are planted at the beginning of a dry season (Frahm *et al.*, 2004). Pigeon pea is a potential crop to cope with changing climate in droughts as it can persist and increase resilience (Kimaro *et al.*, 2016; Saxena *et al.*, 1998).

2.4.2 Effects of planting dates on crop growth and grain yield

Crops need optimum planting time as the deviation from this may lead to yield loss (Brown, 2015; Kamara *et al.*, 2009; Mertz *et al.*, 2009). Early planting produces short plants with small leaf areas and low temperature makes a plant grow slowly (Aldrich *et al.*, 1975). In the growing season where the atmospheric evaporative demand is small, early-planted maize tends to silk earlier (Matzenauer *et al.*, 1998) which effect leaf number and thermal time between female bud differentiation and skin (Otegui & Melon, 1997). Furthermore, planting date affects intercepted photosynthetic active radiation (PAR) and radiation use efficiency (RUE). Dry matter accumulation was reported to be faster before silking and slower after silking in late plantings compared with the early plantings (Cirilo & Andrade, 1994).

Delayed rainfall onset that subjects to late planting window results in a shorter growing season that affects crop growth and yield (Kamara *et al.*, 2009). Late planting of maize prolongs days to flowering hence reduced dry-matter production and yield components (Beiragi *et al.*, 2011; Tefera *et al.*, 2009). The use appropriate CSA practices planted at optimum planting dates such as intercropping supplemented with farm yard manure (FYM) in the open grazing systems has been reported to improve water uptake capacity of fodder crops (Hobbs, 2007). Managing optimum minimum tillage like planting basins and planting date that accord with a given crop requirement can reduce soil erosion and suppress weed. Such combination of CSA practices and planting date would be valuable for improved soil fertility and water productivity and increased crop yield in semi-arid areas and thus make resilience to crops under climate change extremes (ACT, 2008).

2.4.3 Economic benefits for climate smart agriculture (CSA) practices

Making investment decisions about CSA priorities requires understanding trade-offs between promoting one practice versus another, and using the data available to make best-bet decisions in the face of uncertainty (Birol *et al.*, 2010). Cost benefit Analysis (CBA) provides one way of looking in-depth at critical economic factors related to profitability, risk and impact which can be strengthened by the inclusion of analyses of associated environmental and social externalities (Thornton *et al.*, 2018; Tsubo & Walker, 2007; Watkiss *et al.*, 2011). Cost benefit Analysis is an economic tool of choice for evaluating investment decisions (Birol *et al.*, 2010).

The study conducted in Senegal found that there were farm level ecological benefits of CSA practices to compensate the economic benefits at farm level (Boillat & Bottazzi, 2020). A selection of CSA practices that are locally adapted may increase economic benefits for the farmer. The better understanding of CSA practices resilient to climate change may particularly reduce risks of production losses among Small-scale farmers (Arango-Aramburo *et al.*, 2020).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study site

The project was established for the purpose of testing the CSA practices to address the existing knowledge gap by determining the potential benefits and trade-offs of CSA practices under different local conditions by region and production system. Specifically, the study was conducted at Mlali village which lies at latitude 6°16'384"S and longitude 36°44'787"E at an elevation of 1220 m above sea level in Kongwa district, Dodoma region, Tanzania (Fig. 2) in the central zone of Tanzania for 2017/2018 and 2018/2019 cropping seasons.

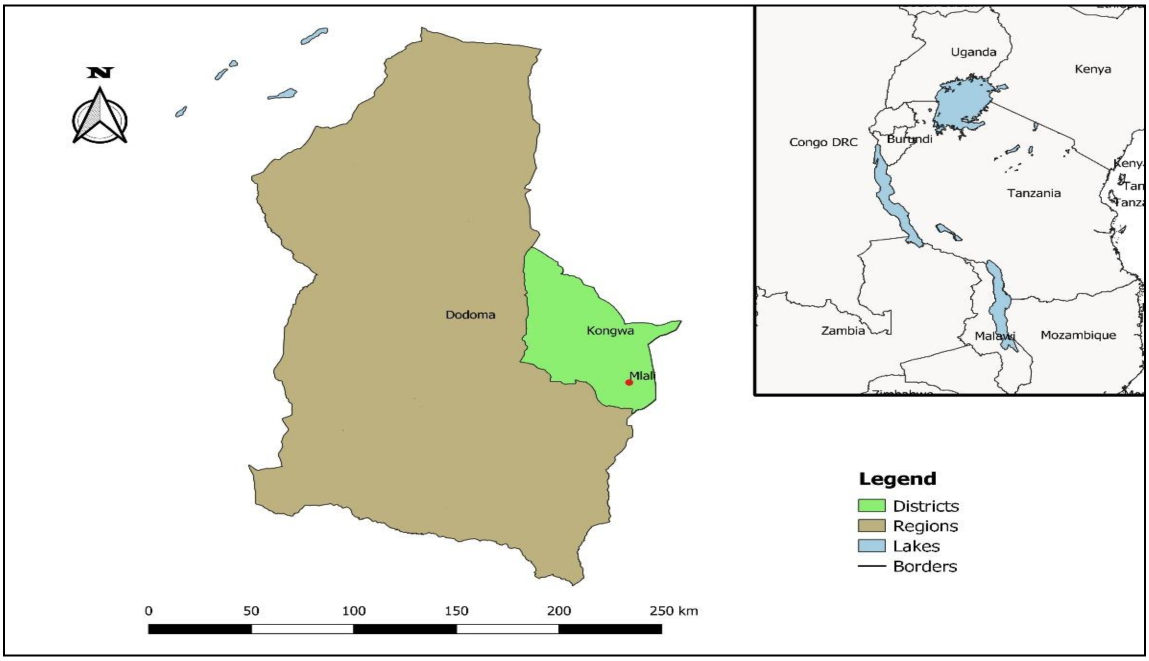

Figure 2: Map of Tanzania, Dodoma Region and Kongwa District indicating the study site Mlali village

3.2 Materials

Maize is the major food and cash crop grown in the study area. Hybrid seed varieties of Maize (*Staha*) was selected as the best fit variety of the study area (MAFS, 2014; Kimaro, 2016) while pigeon pea (ICEAP 0040, *Mali*) is known as a potential variety to cope with changing climate in droughts (Kimaro *et al.*, 2016; Saxena *et al.*, 1998). DAP fertilizer (18 P+46 N+0 K) was applied at a rate of 15 kg P ha^{-1} while Nitrogen (Urea - 46% N) was applied during the fourth week after planting at a rate of 60 kg N ha^{-1} for all treatments.

3.3 Methodology

3.3.1 Site selection

Initially, discussions were held between with ICRAF Tanzania - the project and implementer and the Ministry of Agriculture (MoA), Local Government Authorities through Kongwa District Agricultural, Irrigation and Cooperative Officer (DAICO) on the general overview on agriculture in the study site. The experiment in Kongwa District was conducted at Mlali village which is the former site for Africa RISING project implemented by ICRAF Tanzania. This site was preferred to because it allowed the use of existing farmer network and CSA practices established which were yet not evaluated for crop yields and resilience benefits. Thus, the study site was considered potential due to its uniqueness like being susceptible to droughts, short and unpredictable rainfall pattern, existing farmer's network with basic knowledge in CSA practices in addressing key issues in the dryland agroecology.

3.3.2 Experimental design and treatments

The experiment was laid out in a split-plot design (Appendix 1) with selected CSA practices as treatments (consisting of tied ridges, *chololo* pits, intercropping and ox-cultivation – as a control) assigned as main plots and three planting dates (early, normal and late) assigned as sub-plot replicated three times. The selected four CSA practices were tested across the three planting dates mentioned above. This made a total of 12 treatments which were then randomized in three replications and thus made a total of 36 experimental plots. The decision for planting dates were based on the past 3 decades' rainfall information from 1982 to 2010 collected by Tanzania Meteorological Agency (TMA) cropping seasons for Kongwa district. Similar studies by (EU, 2014) recommends that due to short rain falls during the third week of November to early January, maize sown in mid-December would be exposed to less risks of crop failure thus be reasonable early planting window. The rain onset in mid-December is mostly recognized by farmers in Kongwa as normal planting window however due to shifting in rain onset pattern sometimes it starts much earlier or later to the normal range (Fig. 1).

3.4 Experimental management

3.4.1 Land preparation and planting

The land was prepared two weeks prior to rainfall onset and/or planting whereby in Ox-cultivation practice, land was prepared by using an ox-plough, and hand hoe was used for tied ridges and intercropping CSA practices while for *chololo* pits, a rectangular basin of 20 cm length, 15 widths and 20 cm depth were dug by using a hand hoe. The experimental treatment plot size was the 7 m × 5 m and the unplanted buffer strips between plots and blocks were 1-m and 2 m respectively. For intercropping treatments which involved maize and pigeon peas planted across three planting dates, three seeds were sown per hill at a spacing of 0.6 m within rows and 0.9 m for maize and in alternate rows for pigeon peas. One week after germination, one plant per hole was thinned leaving out 2 plants per hole.

3.4.2 Weeding and fertilizer application (Top dressing)

Manual weed control is the most common method used by farmers in the study area similar to most smallholder farmers in Tanzania. Weeding was done manually by hand hoe two times in the fourth weeks after germination prior to topdressing and the eighth week at pre-tussling stage to avoid competition of resources i.e. light, water, nutrients between weeds and crops and also to improve soil physical conditions. DAP fertilizer (18 P + 46 N + 0 K) was applied as basal fertilizer during planting at a rate of 15 kg P ha^{-1}, then during topdressing Nitrogen source fertilizer (Urea 46% N) was applied at a rate of 60 kg N ha^{-1} in the fourth week after germination that was done immediately after weeding for all treatments.

3.4.3 Pests and diseases control

Pest and diseases control was done by use of pesticides and insecticides effective against detected pests and diseases in the plots. Common pests detected were Crickets (*Gryllus assimilis),* Fall Armyworm (FAW) (*Spodoptera frugiperda*) which mostly affected maize and pigeon peas during germination and vegetative phase respectively. Pesticides and insecticides like Cutter (Acetamiprid 64 g l^{-1} + Emmamectin benzoate 48 g l^{-1}) at a rate of 40 mls 20 l^{-1}, Duduba and Karate (Lambda cyhalothrin) insecticides were applied after every two weeks until tasseling in maize and flowering in pigeon peas was set as recommended by Pipoly *et al.* (2020).

3.5 Data collection

3.5.1 Rainfall information

The daily rainfall was recorded within 24 hours at 0900 am and same time the following day. The rainfall data were recorded from manual rain gauge, installed on a post and placed on the clear ground to avoid errors associated with leaf obstructions.

3.5.2 Soil Sampling and laboratory analysis

Prior to sowing, soil samples at a depth of 0-20 cm were collected from five random points within and outside each block using soil auger for laboratory analysis to establish the initial soil fertility status. These samples were mixed thoroughly and sub-sampled to obtain six composite soil samples whereby to have general soil characteristics of the site, three were from within blocks and other three from outside blocks of the experimental site. The samples were well packed and labelled, and were transported to the soil laboratory at Tanzania Coffee Research Institute (TACRI), Moshi Kilimanjaro, Tanzania. The samples were air-dried and analyzed for Total N, extractable P Bray 1 method, exchangeable bases (Ca, Mg, K and Na) by atomic absorption spectrophotometer after extraction with 1N ammonium acetate. pH, and Cation Exchange Capacity as described by Anderson and Ingram (1993).

3.5.3 Soil Moisture determination

Soil samples were collected in every two weeks after planting to assess soil dynamics for each treatment across the growing season. Soil sampling was done every two weeks from crop emergence of early planting date to its physiological maturity (Karuma *et al*., 2014). Soil samples (at least 50 g) were randomly collected in each treatment, after thoroughly mixed from four points at 0-20 cm depth by using a soil auger within a net area (4 m x 3.6 m). These soil samples were packed in doubled layered plastic bags and shipped to Sokoine University of Agriculture at the department of Ecosystems and Conservation laboratories for soil moisture analysis by the gravimetric method oven dry weight to constant weight at 105 ^{0}C (Karuma *et al.*, 2014; Mkoga *et al.*, 2010). Also, to assess the resilience of established CSA practices on moisture retention capacity and regimes, soil sampling was done even for normal and late planting dates which were not yet planted.

3.5.4 Maize plant growth and yield parameters

The stem girth (mm) and height (cm) of five randomly-selected plants per row within a net area (4 m x 3.6 m) were measured by using a wood a digital Vernier caliper and meter ruler done at flowering stage (Tewodros *et al.*, 2009).

AccuPAR LP-80 Ceptometer (Decagon Divices 2015) was used to measure the Leaf Area Index (LAI) and photosynthetically active radiation (PAR) for the same sampled five maize plants in each CSA treatment as described by Chen (1997). Determination of dry biomass weight of maize plants was done at flowering stage for each CSA practice/treatment within plot net area (4 m x 3.6 m). Days to flowering were determined as the number of days from planting to tasseling of the plants (Tewodros *et al.*, 2009). To achieve this, three plants were sampled from the maize rows and its fresh weights were recorded, packed in a brown paper bag after optimal air dry then shipped to laboratory for oven dry analysis (Ghosh *et al.*, 2017). These samples were oven dried at 70 ºC until constant weight was obtained for determination of whole dry matter yield per each treatment.

Maize plants within a net area (4 m x 3.6 m) were counted and harvested at their full physiological maturity, then maize yield components were partitioned into grain, cobs and stover weighed separately at same time number of cobs were counted and recorded. The subsamples of approximately 200 g for maize grain, three stover and their respective cobs were taken to the laboratory to obtain their oven dry weights at 70 ºC. Its final grain data was adjusted to 12% storage moisture content. Thereafter, dry maize cobs, grain and stover yields result from laboratory were then extrapolated to a hectare (ha) based on yield per sampled net area (4 m x 3.6 m).

Plate 1: Intercropping CSA practices

Plate 2: Tide ridges CSA practices

3.5.5 Assessment of maize nutrient uptake for each treatment

Five maize plants at roasting growth stage in each treatment combination were sampled from the maize rows and their fresh weights were recorded. Prior to analysis, the fresh maize plant samples were washed using distilled water and oven dried of biomass samples at 70 °C for 48 hours to constant weights, then grounded into fine powder passed through 0.5 mm sieve. Thereafter, wet digested for analysis of N by Kjedahl method, P by stannous chlorine P Bray 1 method while K, Mg, and Ca using atomic absorption spectrophotometer procedures as per (Anderson, 1993; Kihara *et al.*, 2015). Nutrient content in this were calculated as a product of biomass (Mg ha^{-1}) and the corresponding concentration of each element and the values were expressed in Kg ha^{-1}. All the procedures for nutrient uptake by maize plant were as per Anderson and Ingram (1993).

3.5.6 Assessment of economic benefits for CSA practices

A market survey conducted during the study period observed that maize grain price including transport to the market at local market known as Kibaigwa cereals market was 0.26 USD/kg. The Marginal Net Return (MRR) were estimated by partial budget technique which considered changes only in costs and returns associated with the treatment application (Mtei, 2013; Ndakidemi *et al.*, 2006).

Marginal net return (MNR) was used to analyze the change across CSA practices, planting dates and their interactions by considering the costs that varies, as reduced cost, income and additional cost were considered. Reduced operational costs were due to reduced number of labour and time used per CSA practice especially during land preparation however all of the CSA practices have the same maintenance costs which is normally done every planting season. Added revenue included the revenue gained from yield increase and added expenses were the cost for labour during for various farming operations (land preparations, planting, pesticides application, weeding and harvesting).

The comparison between the margin net of return and total costs per treatment was done, then the decision on which treatment to adopt was based on the MNR = TR - TVC equation as the positive difference indicates the change is benefitable (Ndakidemi *et al.*, 2006; Kay *et al*., 2008). To compare the additional costs that varied with the benefits, marginal analysis involving dominance analysis was used whereby MRR for each cost un dominated treatments were calculated as the marginal net return (MNR) among treatments divided by the total variable costs (TVC) as described by Mtei *et al.* (2013).

Total variable cost (TVC) were summed from experimental inputs and management costs while output was calculated from maize grain yield (Y) in (kg ha^{-1}), multiplied by its market selling prices (P) in (USD/kg) for 2017/18 and 2018/2019 cropping seasons. Therefore, marginal net return (MNR) was computed for each treatment by the formula whereby $MNR = Y \times P – TVC$, Then the marginal rate of return (MRR) for each treatment was calculated by using the formula: $MRR = MNR/TVC$. Then the recommendations were made based on the comparisons of the marginal rates of return among treatments to the minimum rate of return acceptable to farmers ranging from zero (Birol *et al.*, 2010). As for this study any treatment that has MRR above zero is considered benefitable investment to farmers.

3.6 Statistical analysis

Graphical analysis of residuals was used to test for normality and constant variance before running the analysis of variance (ANOVA). Soil moisture, growth and yield data were normally distributed, thus were subjected to analysis of variance (ANOVA) using the GenStat software (15th Edition) in a Split Plot Design. Significant treatment means separation test were done by using Turkey's-Test at 5% level of significance. Descriptive analysis was conducted on soil moisture levels for each treatment i.e. ox-cultivation - as a control, tied ridges, *chololo* pits and intercropping CSA practices each planted under early, normal and late planting dates. In addition, rainfall data and soil moisture was subjected to descriptive statistics by using Microsoft Excel.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Soil characteristics of the experiment site

The results in Table 1 show the soil characteristics of the experiment site whereby the ratings were according to Landon (1991). Soil was found to be sandy loam soil texture with a pH of 6.2 and rated as slightly acid. Organic carbon content of the soil was 0.39%, rated as very low, total N of the soil was 0.031%, rated as very low and extractable P was 5.38 mg kg^{-1}, rated as low, exchangeable Ca and K were 34 cmol kg^{-1} and 0.35 cmol (+) kg^{-1}, rated as medium. Previously land use on this site was for subsistence farming where maize and pigeon peas were intercropped under ox-cultivation and allow free grazing of livestock after harvesting. However, the farming activities in the study site are severely affected by climatic impacts that affect crop productivity and hence the livelihood of the local farming communities.

Table 1: Soil characteristics of the experiment site

Soil Properties	**Unit**	**Values**	**Soil Fertility rating** (Landon, 1991).
pH (H_20)	-	6.2	Slightly acid
Organic Carbon	%	0.39	Very low
Total Nitrogen	%	0.031	Very low
Exchangeable K	cmol kg^{-1}	0.35	Medium
Exchangeable Na	cmol kg^{-1}	0.31	Medium
Exchangeable Ca	cmol kg^{-1}	34	Medium
Exchangeable Mg	cmol kg^{-1}	1.08	Low
CEC	cmol kg^{-1}	6	High
Bray 1 P	Mg kg^{-1}	5.38	Low
Sand (%)	%	84	
Silt (%)	%	7	
Clay (%)	%	9	
Textural Class		Sandy loam	

Potential of hydrogen (pH), Organ Carbon (OC), Nitrogen (N), Phosphorus (P), Potassium (K), Sodium (Na), Calcium (Ca), Magnesium (Mg), Copper (Cu), Iron (Fe), Manganese (Mn), and Zinc (Zn). Cation Exchange Capacity (CEC). Units for parameters are expressed as percentage (%). Cent moles per kilogram (cmol kg^{-1}) and parts per million (ppm)

4.1.2 Rainfall distribution in the study area

The area receives an average annual rainfall of 570 mm with almost 85% of rain falling between December and April (Fig. 3). Long-term average rainfall recorded by using rain gauges installed at the research site for the five consecutive cropping seasons from 2014-2019 were below the average by 40%. The site received rains mostly in January and March with a dry spell in February that sometimes led to crop failures due to its inconsistence and insufficient soil moisture.

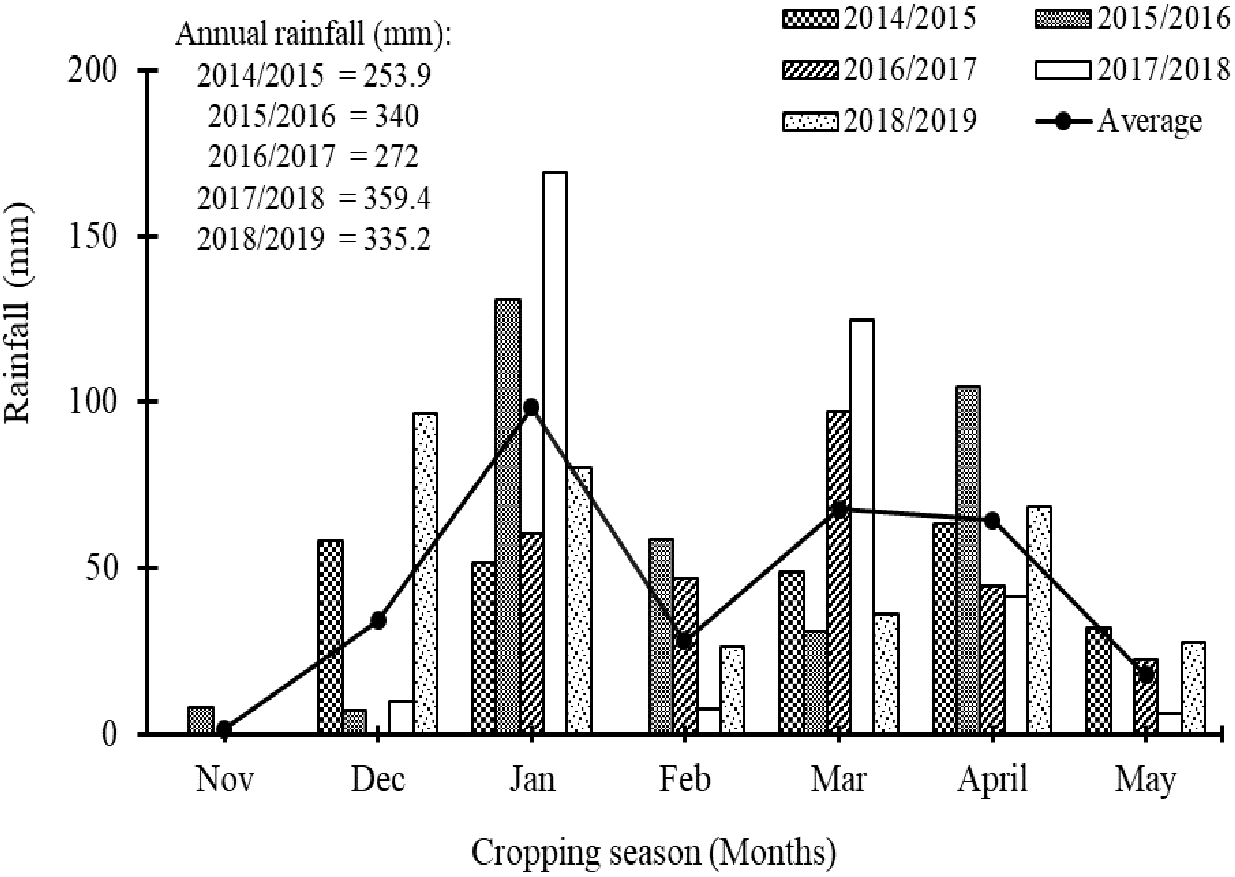

Figure 3: Long-term monthly average (2014/2015–2018/2019) and monthly rainfall recorded during the three consecutive cropping seasons 2016/2017–2018/2019 at Mlali, Kongwa-Dodoma, Tanzania

4.1.3 The effects of CSA practices on soil moisture content

The results on influence of CSA practices and planting dates on gravimetric soil moisture are presented in (Fig. 4, 5, 6 and 7) in both cropping seasons. The study findings reveal that planting date treatments (early, normal and late) varied in soil moisture retention ranging from 2% to 10% and 3% to 12% in 2017/2018 and 2018/2019 cropping season, respectively.

Late planting had the highest soil moisture retention (10.2%) in May 2017/2018 while early planting date resulted into significant difference ($p = 0.034$) soil moisture content (13.17%) in April 2019. In this study, soil moisture dynamics reflect the rainfall patterns for the two cropping seasons of 2017/2018 and 2018/2019 respectively. Among the treatments, it was revealed that *chololo* pits at normal and tied ridges at early planting dates had resilient high soil moisture retention of 10.26% and 10.25% in January for the two cropping seasons (Fig. 6 and 7). Generally, based on monthly soil moisture dynamics, there were a slight increase of 2% on soil moisture retention for *chololo* pits and tied ridges across the planting dates. *Chololo* pits and tied ridges performed better almost in all parameters tested as compared with ox-cultivation and intercropping CSA practices. Figure 6 and 7 shows that there was higher amount of soil moisture content in *chololo* pits and tied ridge across different planting dates which depicts their resilience effects and water conservation capacity. Higher soil moisture content was recorded in months of January, March and April for 2017/18 season and January, February and May for 2018/2019 cropping season in *chololo* pits at early and tied ridges at late planting dates (Fig. 3).

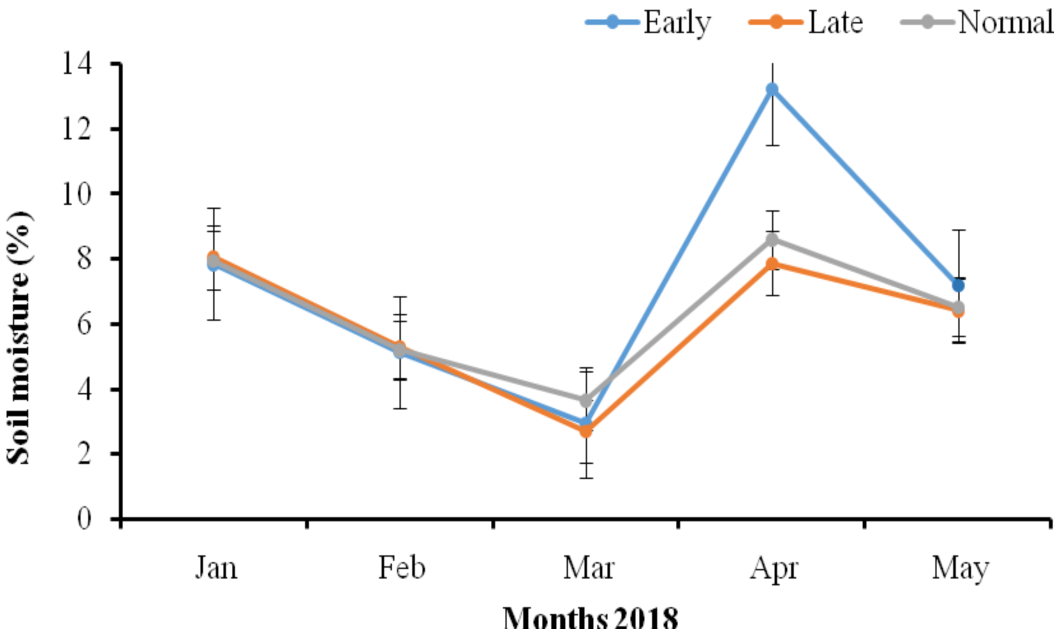

Figure 4: Effects of Planting dates on gravimetric soil moisture at Mlali village during 2017/18 cropping season (n = 3)

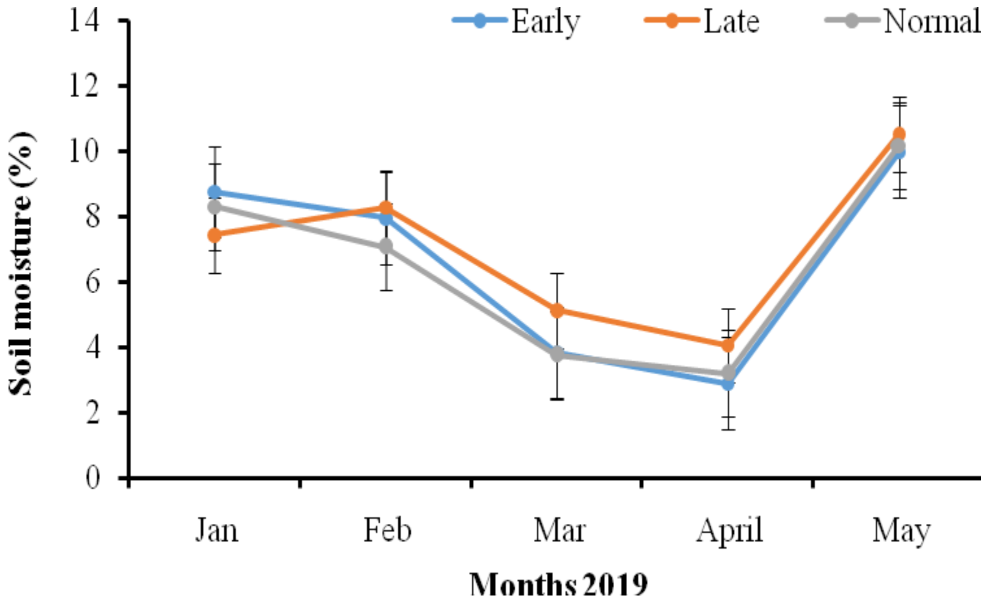

Figure 5: Effects of Planting dates on gravimetric soil moisture at Mlali village during 2018/19 cropping season (n = 3)

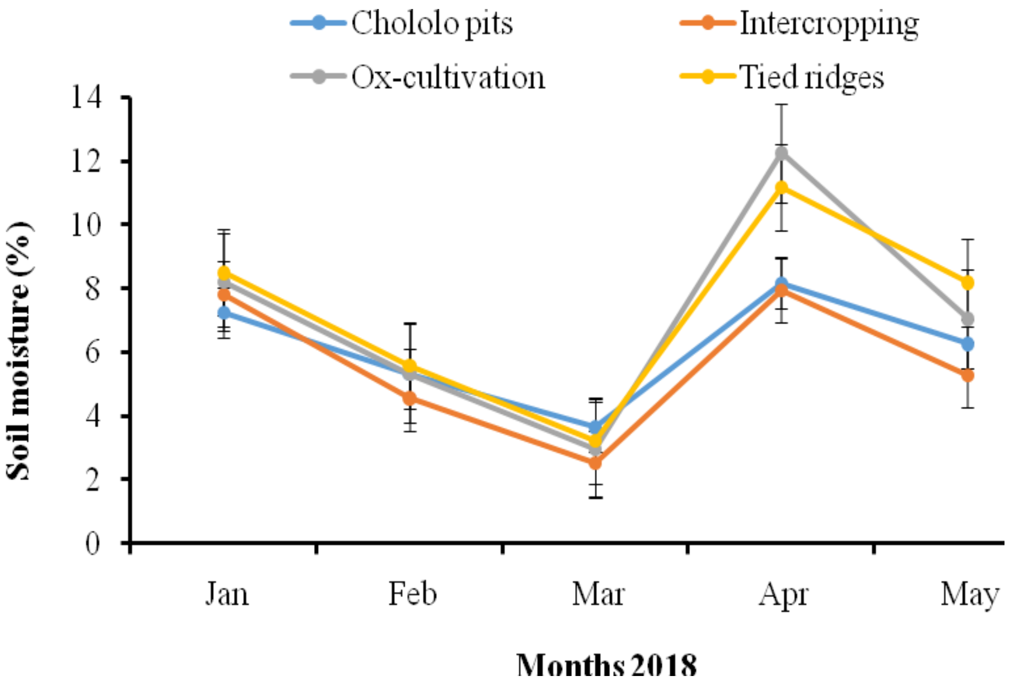

Figure 6: Effects of CSA practices on gravimetric soil moisture at Mlali village during 2017/18 cropping season (n = 3)

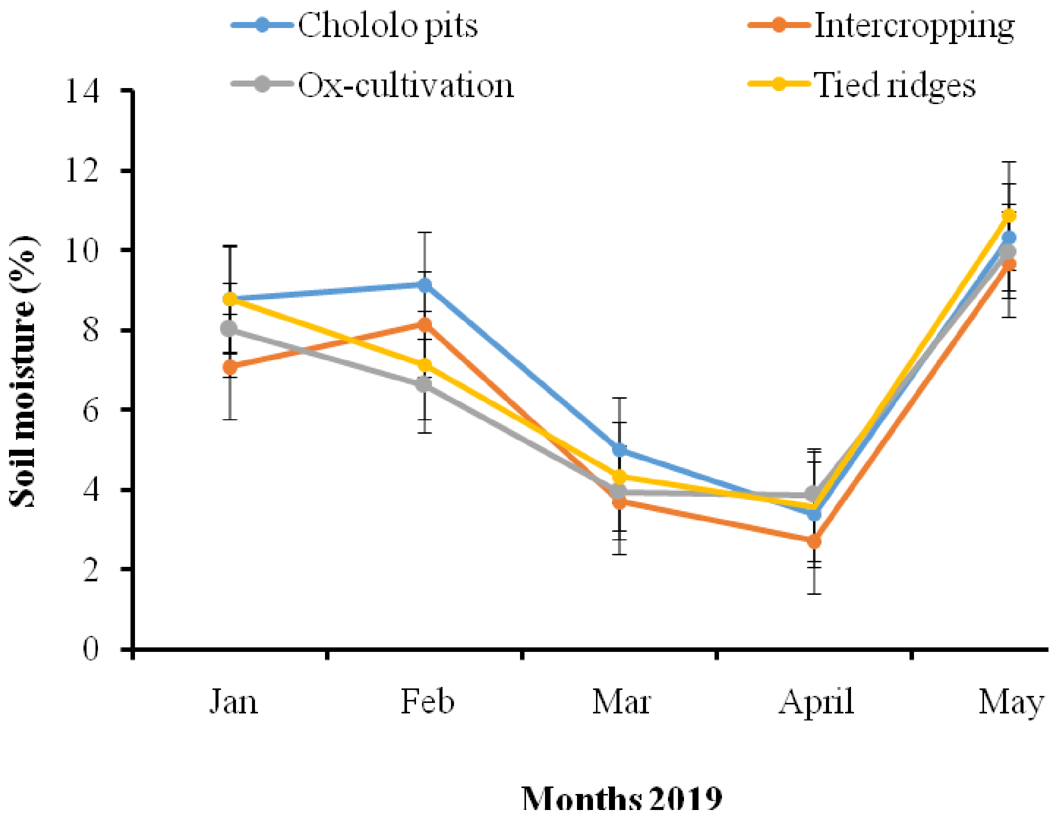

Figure 7: Effects of CSA practices on gravimetric soil moisture at Mlali village during 2017/19 cropping season (n = 3)

4.1.4 Growth and yield parameters of maize crop under selected CSA practices

The study assessed the resilience and economic benefits of Climate Smart Agriculture practices under treatments (ox-cultivation, tied ridges, *chololo* pits and intercropping) and three planting dates (early, normal and late) for two cropping seasons. The results showed that there were significant differences on growth and yield parameters across the treatments. The parameters included were maize plant stem girth, height, LAI, biomass at 50% flowering, cob number, grain and stover/biomass weight at harvesting. The results showed that CSA practices and planting dates were significantly different (p < 0.05) on LAI and biomass.

Maize stem girth: The results for maize stem girth under selected CSA practices, planting dates and their interaction are shown in Table 2. In 2017/2018 cropping season, CSA practices significantly (p = 0.009) affected maize stem girth while in 2018/2019 cropping season CSA practices had no significant effect on maize stem girth. Planting dates had highly significance differences in both cropping seasons whereby p = 0.024 in 2017/2018 and p = 0.007 in 2018/2019 cropping seasons on average stem girth of maize plant. Interaction between CSA practices and planting dates, in 2017/2018 cropping season were not significant difference as compared with 2018/2019 cropping season whereby the interaction between CSA practices and planting dates were significant difference (p = 0.037) on maize stem girth (Fig. 8). However, the results show that *chololo* pits and tied ridges CSA practices had the highest stem girth in both cropping seasons at 24.71 mm and 23.50 mm in 2017/2018 seasons respectively. Resiliently similar CSA practices i.e. *chololo* pits and tied ridges had the highest stem girth of 20.54 mm and 20.39 mm in following 2018/2019 cropping season.

Across planting dates, the results show that normal and late planting dates consistently maintained a comparatively higher stem girth at 21.71 mm and 23.50 cm in 2017/2018 and same increase at 20.49 mm and 20.86 mm in 2018/2019 cropping season while decline trend were noted in early planting date. In both cropping seasons the results (Table 2), depict that the interaction between *chololo* pits and tied ridges CSA practices and late planting dates performed better on stem girth as compared with intercropping and ox-cultivation at early planting dates during this study.

Maize plant height: Results on the influence of CSA practices in combination with planting dates on maize plant height are presented in (Table 2). In both cropping seasons planting dates significantly (p < 0.001) increased maize plant height. However, CSA practices and their interactions between CSA practices and planting dates did not significantly ((p > 0.05) influence plant height. Generally, for the two cropping seasons, the highest maize plant heights were 101 cm and 96.83 cm in *chololo* pits and tied ridges CSA practices respectively. Based on planting date alone, the highest maize plant height was in late planting with 95.99 cm and 91.35 cm followed by early planting date with 87.81 cm and 83.5 cm in both cropping seasons. The results show that in the first season plant height increased among CSA practices whereby *chololo* pits at 45%, tied ridges at 38.3% and intercropping at 27% as compared with ox-cultivation. Similarly, in the second season plant height increased at 41% in *chololo* pits, 47.5% in tied ridges and 30% in intercropping as compared to ox-cultivation. Similar to early and late planting date maize plant increased height at 4% and 14% as compared to normal planting date respectively in both cropping seasons. Their interaction showed that *chololo* pits at late planting increased plant height by 76% followed by tied ridges at late (56%) and *chololo* pits at early (53.3%) as compared to ox-cultivation at late planting date (4%) and ox-cultivation early planting date (13%). However, results in table 2 show that, maize plant height was not significantly different (p > 0.05) both in planting date and the interaction of CSA practices and planting dates.

Leaf Area Index: In both cropping seasons, Climate Smart Agriculture (CSA) practices and Planting dates significantly (p = 0.034 and p = 0.022) increased the leaf area index of maize crops (Table 2). However, the combination of CSA practices and planting dates resulted to no significant difference ($p > 0.05$). Leaf Area Index (LAI) for the tested CSA practices ranged from 0.8 to 1.1 in 2017/2018 and 1.25 to 1 in 2018/2019 cropping seasons. For planting dates LAI ranged from 0.6 to 1.1 and from 1.2 to 1.6 for 2017/2018 and 2018/2019 cropping seasons while in the combination of these CSA practice LAI ranged from 03 to 1.6 in 2017/2018 and from 1.07 to 1.76 in 2018/2019 cropping season. The highest value of LAI was recorded from intercropping (1.01) in 2017/2018 and tied ridges (1.00) in 2018/2019. Table 2 shows overall, tied ridges increased LAI by 43% as compared by intercropping, early planting window had less leaf area index at 51% between 2017/2018 and 2018/2019 and their combination showed tied ridges at early planting increased leaf area index by 48% when compared with ox-cultivation at early planting.

Biomass: In 2017/2018 CSA practices and planting dates had significant differences at p = 0.002 and p = 0.008 (Fig. 8). Similar to 2018/2019 cropping season whereby CSA practices and planting dates were significant at p = 0.008 and p = 0.002 respectively on biomass at 50% flowering (Table 2). Also, in both cropping seasons the interaction between CSA practices and Planting date were significant difference (p = 0.048) respectively on maize biomass (Fig. 9 and 10). Above ground maize biomass at 50% flowering s increased from 1.3 t ha^{-1} to 1 t ha^{-1} in 2017/2018 and from 0.93 t ha^{-1} to 1.16 t ha^{-1} in 2018/2019 cropping seasons across treatments i.e. *chololo* pits, tied ridges and intercropping as compared to ox-cultivation. Similarly, in planting dates, above ground biomass increased at a range of 1.3 t ha^{-1} to 11 t ha^{-1} in 2017/2018 and from 0.96 t ha^{-1} to 1.18 t ha^{-1} in 2018/2019 cropping seasons respectively (Fig. 8 and 9). The lowest dry biomass (1.2 t ha^{-1}) was obtained under intercropping in both season that was 1.5 t ha^{-1} in 2017/18 and 1.2 t ha^{-1} in 2017/2018/19 cropping season. In both cropping seasons, normal planting dates had a lowest dry biomass (1.3 t ha^{-1}) similar to their combination intercropping at normal planting date depicts the lowest dry biomass (0.93 t ha^{-1}).

Table 2: Main, sub and interaction effects of CSA practices on maize growth components for the 2017/2018 and 2018/2019 growing seasons at Mlali village Dodoma, Tanzania. Means with different letters indicate statistical differences (*p* = 0.05)

	2017/2018 Cropping season				2018/2019 Cropping season			
	Stem girth (mm)	**Plant height (cm)**	**Leaf Area Index (%)**	**Biomass (t ha^{-1})**	**Stem girth (mm)**	**Plant height (cm)**	**Leaf Area Index (%)**	**Biomass (t ha^{-1})**
CSA practices (CSA)								
Intercropping	21.41a	89.41b	1.01a	1.264a	20.06a	85.13b	1.252a	0.93a
Ox-cultivation	19.22ab	69.96a	1.06a	1.36ab	19.2a	65.66a	1.315a	1.026ab
Tied ridges	23.50b	96.86b	0.89a	1.452b	20.39a	926b	1.499a	1.119b
Chololo pits	24.71b	101.61b	0.7a	1.489b	20.54a	96.83b	1.398a	1.156b
LSD	2.478	14.308	0.381	0.131	1.488	6.867	0.28	0.131
CV (%)	5.3	16.4	42.3	9.7	7.6	17.1	20.9	12.7
P-Value	0.009	<.001	0.229	0.002	0.27	<.001	0.311	0.008
Planting date (PD)								
Normal	21.79ab	848a	17ab	114b	20.49a	80.20a	1.358ab	1.181ab
Early	21.34a	87.81a	1.086b	1.294a	18.79a	83a	1.194a	0.960a
Late	23.28b	95.99a	0.664a	1.366a	20.86b	91.35a	146b	1.032b
LSD	1.388	12.391	0.33	0.114	1.289	5.947	0.242	0.114
CV (%)	5.6	16.4	42.3	9.7	7.6	17.1	20.9	12.7
P-Value	0.024	0.168	0.034	0.008	0.007	0.184	0.022	0.002
Interaction: CSA x PD								
LSD	3.091	24.781	0.66	0.228	2.578	11.894	0.484	0.228
CV (%)	7.2	16.4	42.3	9.7	7.6	17.1	20.9	12.7
P-Value	0.227	0.345	0.181	0.048	0.037	0.369	0.388	0.048

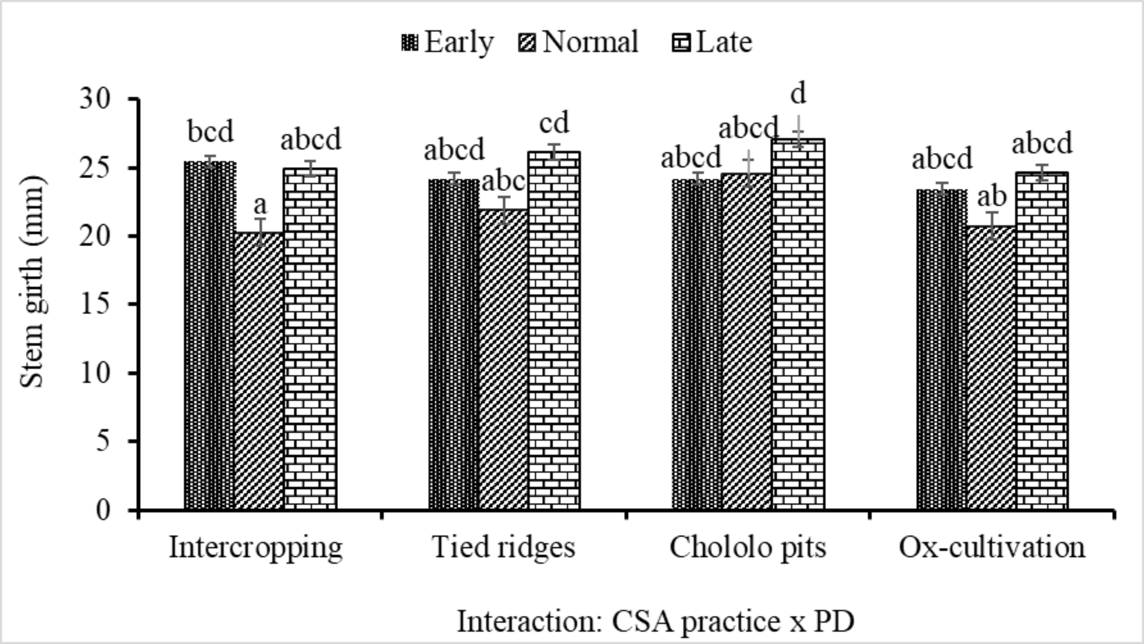

Figure 8: Effects of interaction between CSA practices and Planting date (PD) on Maize stem girth at Mlali village determined during 2018/2019 cropping season (n = 3). Means with different letters indicate statistical differences (*p* = 0.05)

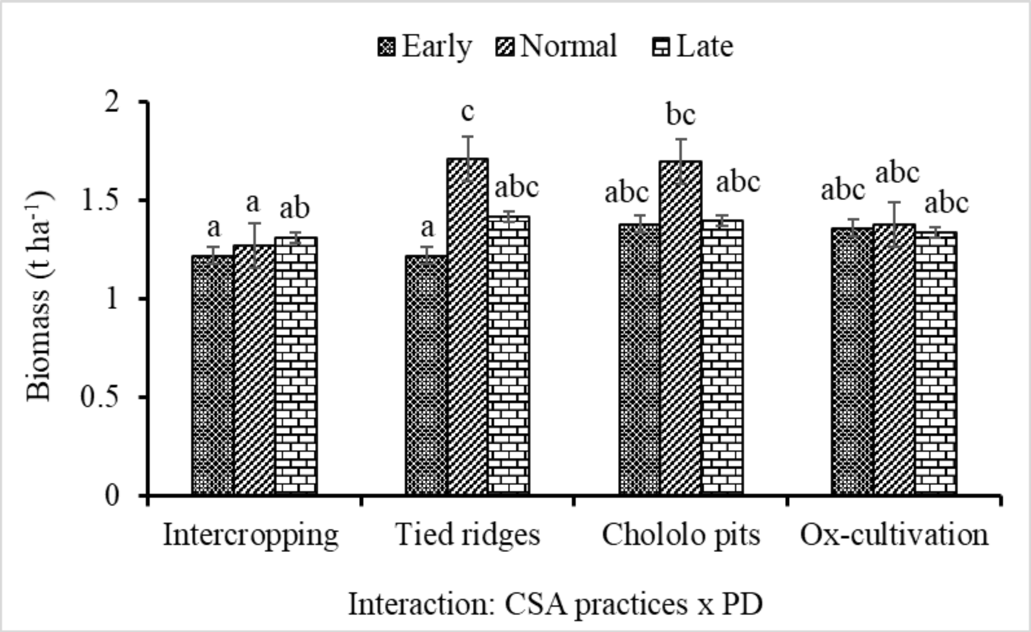

Figure 9: Effects of interaction between CSA practices and planting date (PD) on Maize biomass at Mlali village determined during 2017/2018 cropping season (n = 3). Means with different letters indicate statistical differences (*p* = 0.05)

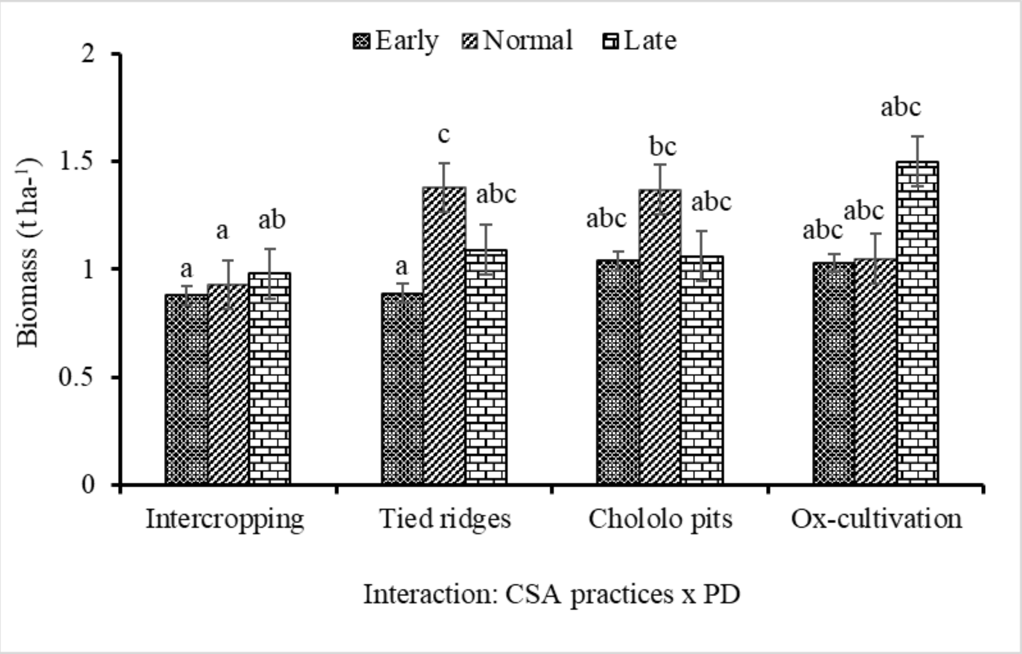

Figure 10: Effects of interaction between CSA practices and planting date (PD) on Maize biomass at Mlali village determined during 2018/2019 cropping season (n = 3). Means with different letters indicate statistical differences (*p* = 0.05)

Maize cobs: Results in Table 3, Fig. 11 and 12 show that in both cropping seasons, CSA practices were significant difference ($p < 0.001$) and ($p = 0.003$) on number of cobs per plot in 2017/2018 and 2018/2019 cropping seasons at harvest respectively. Similarly, planting dates significantly ($p = 0.002$) and ($p < 0.001$) affected number of maize cobs per plot at harvest in 2017/2018 and 2018/2019 cropping seasons respectively. In both cropping seasons (Fig. 11 and 12) the interaction between CSA practices and planting dates on number of maize cobs were also significant difference ($p = 0.039$) in 2017/2018 and ($p = 0.005$) in 2018/2019 respectively. In both cropping seasons there were a consistently increase in number of maize cobs per plot at harvest whereby *chololo* pits and tied ridges CSA practices had the highest number of cobs per plot i.e. 51 cobs and 49 maize cobs in 2017/2018 and 52 and 48 maize cobs in 2018/2019 cropping season respectively. Intercropping and ox-cultivation had the lowest number of maize cobs at late and early planting dates compared with mid planting date treatments (Table 3, Fig. 11 and 12). This implies that treatments with the highest cob numbers were also the highest grain yield treatments.

Maize grain: In 2017/2018 cropping seasons, both CSA practices and planting dates were significantly ($p = 0.049$) and ($p = 0.047$) affected maize grain respectively. However, in 2018/2019 cropping season only planting date was significant difference ($p = 0.001$) contrary to 2017/2018 cropping season where both CSA practices and planting dates were significant different on maize grain. Overall maize grain yield under *chololo* pits and tied ridges were considerably higher than corresponding yields under ox-cultivation and intercropping CSA practices for the two consecutive (2017/2018 and 2018/2019) cropping seasons (Table 11).

Based on CSA practices (*chololo* pits and tied ridges) maize grain yield ranged from 3 t ha^{-1} to 4.7 t ha^{-1} in 2017/2018 and from 1.7 t ha^{-1} to 2.8 t ha^{-1} in 2018/2019, then planting dates ranged from 3 to 4.1 t ha^{-1} in 2017/2018 and 1.4 t ha^{-1} to 2.8 t ha^{-1} in 2018/2019 while maize grain yield of the interaction of CSA practices and planting dates ranged from 3.09 t ha^{-1} to 5 t ha^{-1} in 2017/2018 and 0.96 t ha^{-1} to 3.6 t ha^{-1} in 2018/2019.

Generally, *chololo* pits and tied ridges consistently resulted in higher maize grain yields at 3.66 t ha^{-1} and 4.7 t ha^{-1} respectively in 2017/2018. Similar trend was noted at 2.75 t ha^{-1} and 2.25 t ha^{-1} in 2018/2019 cropping season (Table 3). Maize grain yield in 2017/2018 cropping season was relatively higher two-folds of the 2018/2019 cropping season as this might have been associated with poor rainfall distribution across the two cropping seasons (Fig. 3). *Chololo* pits and Tied ridges increased maize grain yield by 12% and 2.3% respectively as compared with ox-cultivation in both cropping seasons. Although the combination of CSA practices and planting dates was not significantly different ($p > 0.05$) on maize grain yield, CSA practice specifically intercropping reduced maize grain yield by 25% and 10% in 2018 and 2019 cropping seasons respectively. Unlike, there was increase in maize grain yield by 10% at early and 13% at late planting dates respectively as compared to Normal planting that reduced maize grain yield at 37%.

Maize Stover: In 2017/2018 cropping season, only CSA practices was significantly (p = 0.01) increased maize stover yield. Climate-Smart Agriculture (CSA) practices, planting dates and their combination in 2018/2019 cropping season were not significantly difference. Tied ridges had the highest stover yield of 8.2 t ha^{-1} and 3.9 t ha^{-1} in 2017/2018 and 2018/2019 cropping seasons respectively. Similar trend in 2018/2019 cropping season was noticed in *chololo* pits (3.332 t ha^{-1}) which were relatively low as compared with ox-cultivation and intercropping CSA practices. Maize stover yield across CSA practices ranged from 6 t ha^{-1} to 9.4 t ha^{-1} in 2017/2018 and 3.3 t ha^{-1} to 4 t ha^{-1} in 2018/2019 cropping seasons respectively. Moreover, stover yields under planting dates ranged from 33 to 4.13 t ha^{-1} in 2017/2018 and 1.35 t ha^{-1} to 2.78 t ha^{-1} in 2018/2019 while their interaction between CSA practices ranged from 3.09 t ha^{-1} to 5.47 t ha^{-1} in 2017/2018 cropping season and 0.96 t ha^{-1} to 3.6 t ha^{-1} in 2018/2019 cropping season (Table 3).

Table 3: Main, sub plots and interaction effects of CSA practices on maize yield parameters for the 2017/2018 and 2018/2019 growing seasons at Mlali village Dodoma, Tanzania. Means with different letters indicate statistical differences (p = 0.05)

	2017/2018 cropping season			2018/2019 cropping season		
	Mean Cob No	**Mean Grain Yield (t ha^{-1})**	**Mean Stover Yield (t ha^{-1})**	**Mean Cob No**	**Mean Grain Yield (t ha^{-1})**	**Mean Stover Yield (t ha^{-1})**
CSA practices						
Intercropping	37.89a	2.987a	6.624 a	38.33a	1.66a	3.574 a
Ox-cultivation	40.00a	3.739ab	5.997 a	39.89a	1.975a	3.822 a
Tied ridges	48.89b	4.717b	8.165 ab	48.33b	2.246a	3.908 a
Chololo pits	50.78b	3.86ab	9.383 b	52.00b	2.747a	3.332 a
LSD	9.72	1.194	1.705	5.651	1.149	1.29
CV (%)	4.3	32.3	20.9	6.3	26.7	17.6
P-Value	<.001	0.049	0.01	0.003	0.227	0.704
Planting date (PD)						
Normal	39.50a	4.127a	7.028a	39.38a	1.347a	4.047a
Early	47.33b	3.674a	7.316a	44.00a	2.343b	3.734a
Late	46.33ab	3.526a	8.283a	50.33b	2.782b	3.197a
LSD	5.68	1.034	1.399	4.092	0.679	1.367
CV (%)	4.3	32.8	20.9	6.3	26.7	38.8
P-Value	0.02	0.0467	0.7	<.001	0.001	0.43
Interaction: CS x PD						
LSD	9.72	2.067	2.486	8.118	1.435	2.486
CV (%)	14.3	32.8	20.9	10.6	39.3	40.1
P-Value	0.039	0.963	0.153	0.005	0.212	0.659

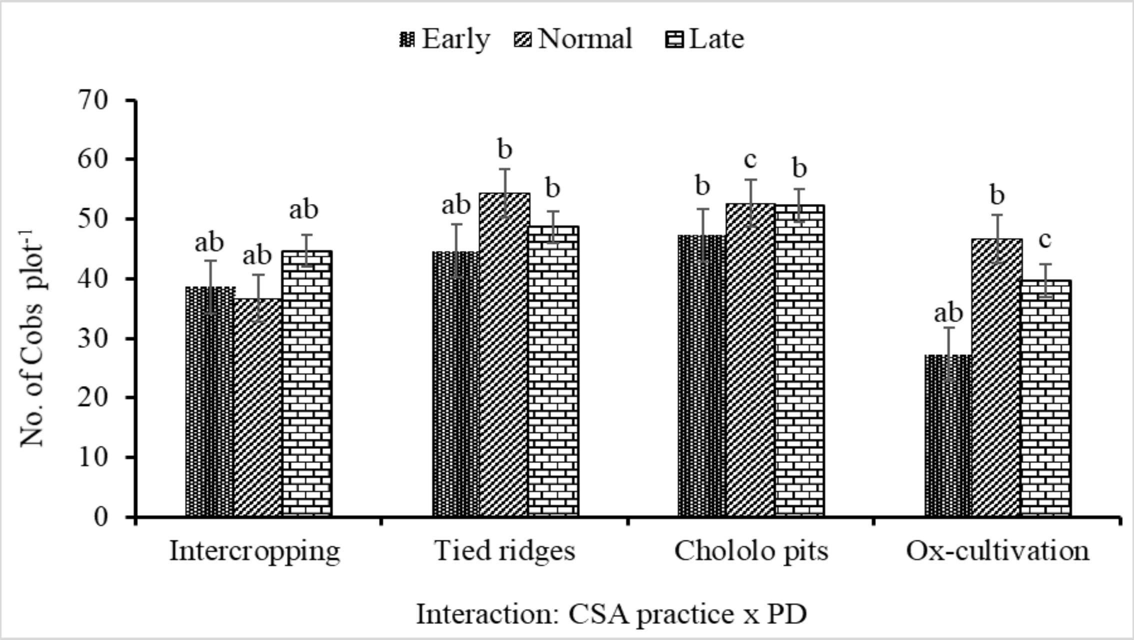

Figure 11: Effects of interaction between CSA practices and planting date on number of maize cob per plot at Mlali village determined during 2017/2018 cropping season (n = 3). Means with different letters indicate statistical differences (*p* = 0.05)

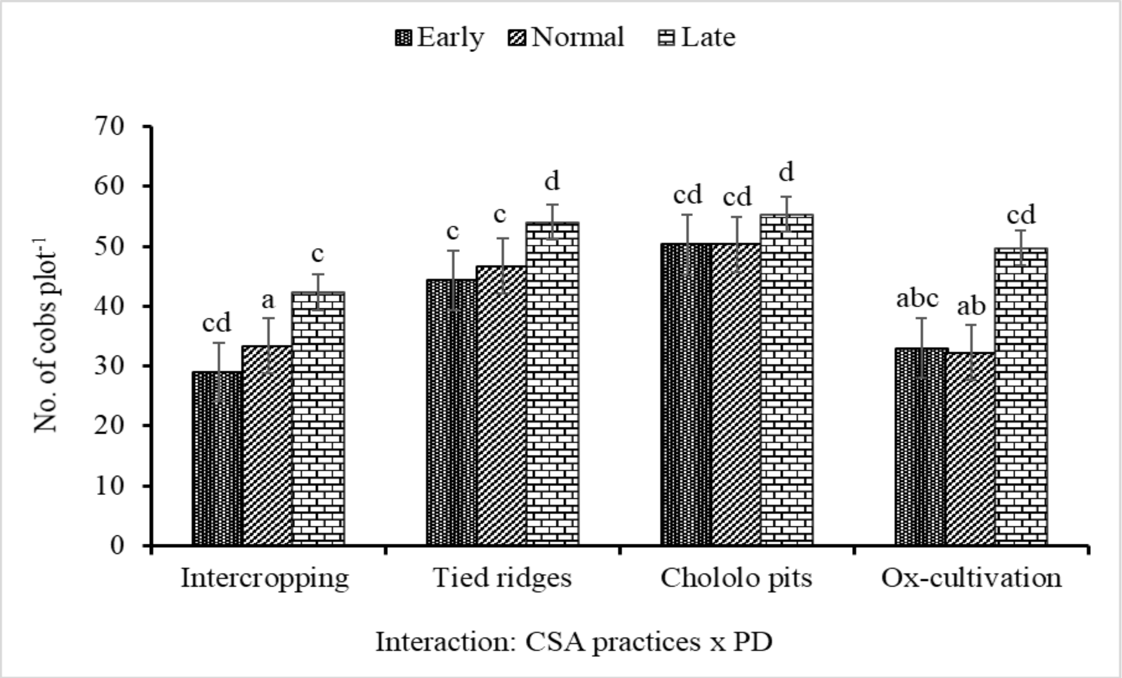

Figure 12: Effects of interaction between CSA practices and planting date on number of maize cob per plot at Mlali village determined during 2018/2019 cropping season (n = 3). Means with different letters indicate statistical differences (*p* = 0.05)

4.1.5 Effects of CSA practices on maize nutrient uptake

The results in Table 4, show that CSA practices had a significant (*p* = 0.006) effect on Nitrogen (N) nutrient uptake. Alike, Magnesium (Mg) nutrient uptake were significantly affected by both CSA practices (*p* = 0.05) and Planting dates (*p* = 0.048). Also, there were significant differences (*p* = 0.038) for the interaction between CSA practices and planting dates on Phosphorus (P) nutrient uptake by maize plant (Fig. 13). Although the interaction between CSA practices and planting date were not significant on N, K, Mg and Ca nutrient uptake (Table 4).

Nitrogen (N), Potassium (K) and Magnesium (Mg) were high in ox-cultivation CSA practices followed by *chololo* pits practices, whereby *chololo* pits and Tied ridges had the higher amount of Phosphorus (P) and Calcium (Ca) nutrient uptake by maize plant. Nutrient uptake by maize plant ranged from 5.5 kg ha^{-1} to 10 kg ha^{-1} across CSA practices, whereby *chololo* pits and ox-cultivation had the highest N uptake at 9.8 kg N ha^{-1} and 9.2 kg N ha^{-1} respectively.

Planting date had the nutrient uptake ranged from 0.9 kg ha^{-1} to 9 kg ha^{-1} whereby normal planting date resulted into the highest nutrient uptake as compared with early and late planting dates. Magnesium (Mg) nutrient uptake was significantly affected by planting date with the highest 2.47 kg Mg ha^{-1} at late planting window absorbed by maize plant. Early planted maize resulted into higher amount of P uptake by the plant (at 2.5 kg P ha^{-1}) which is 0.58% increase when compared with nutrient uptake under early planting date (1.89 kg ha^{-1}).

Table 4: Biomass yield (t ha^{-1}) and nutrient uptake (kg ha^{-1}) of maize for 2018/19 cropping season under different CSA practices planting date treatments at Mlali Dodoma, Tanzania

Treatment	Maize					
	Biom.	N	P	K	Mg	Ca
CSA practices						
Intercropping	0.93a	5.46a	4.17a	1.963a	1.90a	0.297a
Ox-cultivation	1.026ab	9.15b	4.47a	2.653a	2.44b	0.263a
Tied ridges	1.119b	8.95b	45a	257a	2.36b	0.362a
Chololo pits	1.156b	9.82b	5.40a	2.337a	2.35b	0.344a
LSD	0.131	1.980	0.938	0.973	000	0.103
CV (%)	14.3	42.2	25.9	28.4	25.6	38
P-Value	0.002	0.006	0.094	0.315	0.05	0.177
Planting date (PD)						
Normal	1.181b	9.04a	5.309a	2.493a	2.42a	2.423a
Early	0.960a	7.11a	4.217a	2.127a	1.89a	1.892a
Late	1.032ab	8.88a	4.409a	213a	2.47b	2.470a
LSD	0.114	3.046	1.040	084	000	0.106
CV (%)	14.3	42.2	25.9	28.4	25.6	38
P-Value	0.008	0.355	0.089	0.315	0.048	0.945
Interaction: CSA x PD						
LSD	24.8	0.135	0.0256	0.617	0.586	0.248
CV (%)	16.4	42.2	25.9	28.4	25.6	38
P-Value	0.345	0.436	0.038	0.185	0.172	0.148

Organ Carbon (OC), Nitrogen (N), Phosphorus (P), Potassium (K), Sodium (Na), Calcium (Ca), Magnesium (Mg), Copper (Cu), Iron (Fe), Manganese (Mn) and Zinc (Zn). Units for parameters are expressed as percentage (%). Cent moles per kilogram (cmol kg^{-1}) and parts per million (ppm)

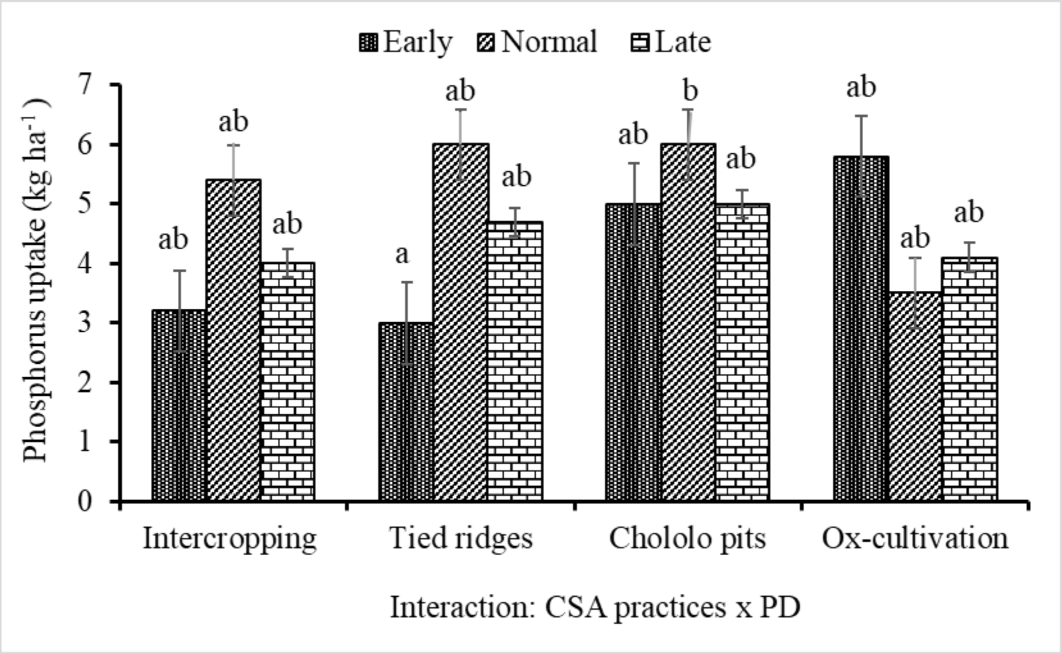

Figure 13: Effects of interaction between CSA practices and planting date on Phosphorus (P) nutrient uptake by maize at Mlali village during 2018/2019 cropping season (n = 3). Means with different letters indicate statistical differences (*p* = 0.05)

4.1.6 Economic assessment of climate smart agriculture (CSA) practices

The study assessed economics of CSA practices (ox-cultivation, tied ridges, *chololo* pits and intercropping) and three planting dates (early, normal and late) for two cropping seasons. The result shows that CSA practices varied in total variable costs. In the order *chololo* pits (518 USD ha^{-1}), tied ridges (513 USD ha^{-1}) and intercropping (419 USD ha^{-1}) and similar trend was observed in their marginal net return (MNR). Total variable costs in planting dates were slightly different but there was typical variation in marginal net return ranging from 440 USD ha^{-1} to 540 USD ha^{-1} across planting dates i.e. marginal net return in early planting date (583 USD ha^{-1}) normal planting date (441 USD ha) and late planting date (659 USD ha). Further assessments were made on the marginal rates of return (MRR) among treatments. Marginal rate of return (MRR) shows how revenue able to cover all total variable cost of a treatment and by how many time (CIMMYT, 1988). Thus, for this study any treatment that has MRR above zero is considered benefitable investment and vice versa by farmers.

Costs - Benefit Analysis of the selected CSA practices: In both cropping seasons (2017/2018 and 2018/2019), total variable costs (TVC) were significantly affected ($p < 0.05$) by Climate smart agriculture (CSA) practices. There were higher TVC in *chololo* pits and tied ridges

CSA practices while intercropping had the lowest costs as compared with ox-cultivation CSA practices. Table 5, show that, *chololo* pits and tied ridges CSA practices had the highest TVC by 526.17 USD ha^{-1} and by 515.30 USD ha^{-1} respectively in 2017/2018 cropping season.

In 2018/2019 cropping season, both *chololo* pits and tied ridges had TVC of 510.52 USD ha^{-1} followed by 509.86 USD ha^{-1} and 485.52 USD ha^{-1} in 2018 and 2018/2019 cropping seasons respectively in intercropping CSA practice. Generally, in 2018 and 2018/2019 cropping seasons, the TVC in *chololo* pits increased by 2.1% and 6.3%, tied ridges by 2.8% and 6.3% while the decrease in total variable costs by 1.7% and 1.12% was noted on intercropping CSA practice in the 2018 and 2018/2019 cropping season, respectively.

The Marginal Net Return was higher in tied ridges at 715.22 USD ha^{-1}, *chololo* pits at 480.79 USD ha^{-1}, followed by ox-cultivation at 474.17 USD ha^{-1} whereby intercropping had the lowest MNR of 269.35 USD ha^{-1} in 2018 cropping season. Dissimilar to 2018/2019 cropping season, there was less MNR as compared with 2018 cropping season (Table 5). However, CSA practices consistently increased MNR in the tied ridges by 75.40 USD ha^{-1}, *chololo* pits by 206.09 USD ha^{-1}, ox-cultivation by 35.08 USD ha^{-1} while intercropping CSA practice made loss by 52.47 USD ha^{-1}.

Marginal rate of return (MRR) was significantly affected ($p < 0.05$) by CSA practices whereby in both cropping season tied ridges and *chololo* pits had the highest MRR. But MRR was less in intercropping CSA practices (0.53) in 2018 cropping season while in 2018/2019 cropping season failed to cover the total variable costs of at - 0.12 (Table 5).

In this study, the results show that MRR increased across CSA practices whereby in 2018 cropping season tied ridges (1.39), *chololo* pits (0.91), and Ox-cultivation (0.94) compared with less MRR in 2018/2019 cropping season whereby, tied ridges (0.15), *chololo* pits (0.4), and Ox-cultivation (0.07). Among CSA practices, intercropping resulted into the lowest MRR in both cropping seasons at 0.53 in 2017/2018 and negative 0.12 in 20187/2019 cropping season (Table 5).

In this study the average total variable costs of the treatment, ranged from 1.4% to 5.7%. Specifically, *chololo* pits increased TVC by 5.6%, followed by tied ridges by 4.5% and the lowest cost was in intercropping by 1.6% comparative to ox-cultivation. Also, MNR increased from 34% to 55% between tied ridges and *chololo* pits respectively while intercropping generated negative MNR of 43% as compared to the rest tested CSA practices.

Table 5: Total variable costs, marginal net return and marginal rate of returns (USD) of selected CSA practices for 2017/18 and 2018/19 cropping seasons. NB: 1 USD = 2300 TZS

CSA practices	2017/2018 Cropping season			2018/2019 Cropping season		
	TVC (USD ha^{-1})	MNR (USD ha^{-1})	MRR	TVC (USD ha^{-1})	MNR (USD ha^{-1})	MRR
Intercropping	509.86	269.35	0.53	485.52	- 52.47	- 0.12
Ox-cultivation	501.22	474.17	0.95	480.14	35.08	0.07
Tied ridges	515.30	715.22	1.39	510.52	75.40	0.15
Chololo pits	526.17	480.79	0.91	510.52	206.09	0.40

Costs and Benefit Analysis of Planting dates as CSA practices: In both cropping seasons, total variable costs (TVC) were not significantly affected ($p > 0.05$) by planting dates. Across all the three planting dates (early, normal and late), the TVC were the same whereby in 2018 cropping season, TVC was 501.22 USD ha^{-1} while in 2018/2019 cropping season was 485.57 USD ha^{-1} respectively. Planting date in 2018/2019 cropping season had lower TVC by 15.65 USD ha^{-1} that is 3.12% decrease as compared with 2018 cropping season. The lower the TVC in 2018/2019 was due to less frequency of pesticides spraying. Also, the average TVC for the two cropping seasons was 493.40 USD ha^{-1} across the tested planting dates was recorded.

The result in Table 6, shows that in 2017/2018 cropping season, the highest MNR was in normal planting date (575 USD ha^{-1}) which outperformed the early planting date (457 USD ha^{-1}) and late planting date (419 USD ha^{-1}). Moreover, in 2018/2019 cropping season normal planting date generated a loss/negative MNR of 132 USD ha^{-1} but early and late planting dates generated a positive MNR of 126 USD ha^{-1} and 240 respectively. In both seasons, generally the average MNR early and late planting dates increased from 32% to 49% for 2018 and 2018/2019 cropping seasons respectively as compared with normal planting dates (Table 6).

Table 6: Total variable costs and marginal net return marginal rate of returns (USD ha^{-1}) under selected planting dates as CSA practices for 2017/18 and 2018/2019 cropping seasons. NB: 1 USD = 2300 TZS

Planting dates	**2017/2018 Cropping season**			**2018/2019 Cropping season**		
	TVC (USD ha^{-1})	**MNR (USD ha^{-1})**	**MRR**	**TVC (USD ha^{-1})**	**MNR (USD ha^{-1})**	**MRR**
Normal	501.22	575.39	1.15	485.57	- 134.18	- 0.28
Early	501.22	457.21	0.91	485.57	125.65	0.26
Late	501.22	418.60	0.84	485.57	240.17	0.50

Costs benefit Analysis of Interaction between CSA practices and Planting dates: In both 2017/18 and 2018/19 cropping seasons, the highest total variable costs were in *chololo* pits at early and late planting dates (526.17 USD ha^{-1} and 510.52 USD ha^{-1}) similar to MNR generated under these respectively. Results in Table 7 showed that, the *chololo* pits at early and tied ridges CSA practices at late planting dates resulted into the highest marginal net return of 841.2 USD ha^{-1} and 691.87 USD ha^{-1} as compared with negative MNR of 135.04 USD ha^{-1} and 202.15 USD ha^{-1} made from intercropping and tied ridges CSA practices at normal planting dates respectively (Table 6). *Chololo* pits and tied ridges CSA practices at early and late planting dates resulted into positive MNR increases by 25.4% and 30.8% respectively. This is contrary to intercropping and tied ridges CSA practices both at normal planting date which made a negative MNR by 63% and 47.7% respectively. The MNR generated for the first season ranged from 175 USD ha^{-1} to 911 USD ha^{-1} while in the second season MNR ranged from -240 USD ha^{-1} to 440 USD ha^{-1} across tested CSA practices i.e. interaction between CSA practices and planting date.

Table 7: Total variable costs, marginal net return and marginal rate of returns (USD ha^{-1}) for the interaction of CSA practices and planting dates for 2017/2018 and 2018/2019 cropping seasons. NB: 1 USD = 2300 TZS

CSA practices	2017/2018 Cropping season			2018/2019 Cropping season		
	TVC (USD ha^{-1})	MNR (USD ha^{-1})	MRR	TVC (USD ha^{-1})	MNR (USD ha^{-1})	MRR
Intercropping Normal	501.22	354.17	0.71	490.95	239.73	- 0.5
Tied ridges Normal	515.30	910.88	1. 77	510.52	206.34	- 0.40
Ox-cultivation Early	501.22	420.95	0.84	485.57	137.05	- 0.28
Ox-cultivation Normal	501.22	502.08	1.17	485.57	-74.18	- 0.15
Chololo pits Normal	526.17	422.88	0.80	510.52	-72.26	- 0.14
Intercropping Early	501.22	304.34	0.61	485.57	27.04	0.6
Intercropping Late	501.22	175.73	0.35	485.57	49.73	0.10
Tied ridges Early	515.30	697.48	1.35	510.52	128.88	0.25
Chololo pits Late	526.17	495.66	0.94	510.52	256.44	0.50
Ox-cultivation Late	501.22	499.73	1.00	485.57	300.43	0.62
Tied ridges Late	515.30	537.31	1.04	499.65	314.79	0.63
Chololo pits Early	526.17	497.74	0.95	510.52	434.09	0.85

4.2 Discussion

4.2.1 Effects of CSA practices, planting date and their interaction on soil moisture content dynamics

Soil moisture dynamics influenced maize grain yield across CSA practices. Soil moisture data under *chololo* pits and tied ridges CSA practices planted at early and late planting dates were resiliently higher in both cropping seasons despite the poor rainfall pattern. Soil moisture under *chololo* pits and tied ridges were significant higher as compared to intercropping and ox-cultivation CSA practices due to higher soil water conservation capacity. Similar to planting dates, the late planting had higher soil moisture content than early and normal planting dates. The higher soil moisture content in months of January, March and April for 2017/18 season and January, February and May for 2018/19 cropping season in *chololo* pits at early and tied ridges at late planting dates might have been influenced by the rainfall distribution (Fig. 3). Generally, *chololo* pits had the highest average soil moisture content followed by tied ridges intercropping and lastly ox-cultivation (control). Higher soil moisture content in *chololo* and tied-ridges reflects moisture conservation benefits of these practices. This aligns with the study by Biazin *et al*. (2012) that *chololo* pits are the most effective water harvesting and soil moisture conservation method in semi-arid areas. The resilience of these CSA practices demonstrated high productivity in grain yield and increased MNR. The better performance is due to its high capacity on soil moisture and rain water use efficiency (Gamba *et al.*, 2020). Such CSA practices are useful as adaptation and mitigation measures of climate change. Early and late planting data recorded the highest soil moisture due to high precipitations at the beginning and end of the growing season with a prolonged drought in February and March. *Chololo* pits consistently maintained a relatively higher soil moisture across these planting dates while a declining trend was noted for tied-ridge and a slight increase in ox-cultivation and intercropping treatments. The lower the soil moisture on tied ridges compared with *chololo* pits would be due to fact that soil on top of ridges loose soil moisture faster than in *chololo* pits and other treatments. A strong relationship was observed between soil moisture and precipitation distribution particularly in the months of January, February and May. This boosted late planting dates at booting and grain filling growth stages, similar to the study in Ethiopia on influence of soil moisture and planting dates by Tewodros (2009) which argues that insufficient soil moisture caused poor grain tasseling and filling at late planting date as they were in a critical stage for cob and grain formation. Similar trend on increase in moisture content observed on grain yield under *chololo* pits and tied ridges at early and late planting dates (Stewart & Steiner, 1990; Tewodros *et al.,* 2009; Yordanov *et al.*, 2000). Overall *chololo* pits and tied ridge holds a promise to mitigate drought conditions and improve resilience of CSA practices in the study site.

4.2.2 Effects of CSA practices, planting date and their interaction on maize plant growth parameters

The poor performance of normal planting dates on maize plant height and stem girth might be associated with poor rainfall distribution and a drought spell in late February to mid-April 2019. Consequently, other maize plant growth parameters (Leaf Area Index, light interception/PAR) were affected by the drought spells which occurred prior to the flowering but plants under *chololo* pits and tied ridges had shown resilience due to its high capacity of soil moisture conservation. Few plant leaves at 50% flowering were affected by drought spell that had influenced light interception and fresh biomass but were promising state in *chololo* pits and tied ridges as compared with ox-cultivation and intercropping CSA practices. *Chololo* pits outperformed tied ridge on maize plant height for the two consecutive cropping seasons, which is expected in drought areas as described by Boillat and Bottazzi *et al*. (2020). Maize plants at 50% flowering stage showed that late planting dates recorded the tallest plant height almost twice of maize plants from early and normal planting date treatments in both cropping seasons. The shorter maize plant height treatments resulted to low grain yield as compared with taller maize treatments. Also, the study by Birch *et al.* (2003); Liebman and Dyck (1993) contends that such shorter plants would be an indicator of low grain yield. However, CSA practices and the interactions between CSA practices and planting dates was not significantly influenced plant height. Maize planted under normal planting window in 2018/2019 cropping season might have stopped growth due to early flowering because of water deficit compared with early and late maize planted (Parthasarathi *et al.*, 2013). Limited water availability to plant during flowering affects its physiological status causing decline in photosynthetic rates and plant growth (Hatfield & Prueger, 2015). Normally under limited water availability normal and progressive drought stress in maize resulted to poor maize plant growth and low yield.

4.2.3 Effects of CSA practices, planting date and their interaction on maize yield parameters

The results presented show that *chololo* pits and tied ridges CSA practices have potential to improve crop production and reduce the risks of crop failure in semi-arid conditions. With regards to this study, crop production is mainly constrained by shifting on rainfall patterns and inappropriate planting dates and this cause crop failure due to water losses during the cropping season. Although there was decline in yield due to delayed rain onset and unreliable rainfall distribution below the average of 40.13% noted during this study, *chololo* pits at early and tied ridges at late planting dates respectively proved the drought resilience capacity to adapt with such climatic extremes. Higher maize stover and grain yield observed in *chololo* pits and tied ridges CSA practices could be attributed to the higher soil moisture capacity of these CSA practices observed during the grain filling stages especially for early and late planting dates. These CSA practices demonstrated their adaptive capacity as resilience on soil water conservation and rain use efficiency that enhanced maize grain yield (Baldé *et al.*, 2011; Berhanu *et al.*, 2020; Sanders, 2000). Previous studies in semiarid areas of West Africa also noted higher sorghum grain yield in Basin pits/Half-moon used as rain water harvesting technologies (Boillat & Bottazzi, 2020). Similarly, this study noted *chololo* pits and tied ridges planted at early and late planting dates respectively significantly ($p < 0.05$) increased maize grain yield for the two consecutive cropping seasons despite the poor rainfall distribution in the two cropping seasons. The better performance of these CSA practices proves their resilience in maintaining higher level of moisture retention as a rainwater harvesting technology in dry areas like Kongwa (Wiyo *et al.*, 2000) despite the grain yield decline in 2018/2019 as compared with 2018 cropping season. In this study, *chololo* pits and tied ridges CSA practices in semi-arid areas showed an increase in grain yield as compared with ox-cultivation/control in both cropping seasons. Poor distributions of rain (Fig. 2) at the critical stages of plant development mainly accounted for low soil moisture and suppressed growth of maize (Birch *et al.*, 2003; Demeke *et al.*, 2011; Karuma *et al.*, 2014) leading to low grain and non-significant maize grain yield under intercropping and ox-cultivation CSA practices. Similar studies on rainwater harvesting in East Africa showed that the higher soil moisture retention in planting basins and tied ridges CSA practices resulted into higher maize grain yield at 6.8% increase for a period of three years (Berhanu *et al.*, 2020; Biazin *et al.*, 2012; Tewodros *et al.*, 2009). These results, however, are in line with high soil moisture at the beginning (December and January) and towards the end (End of March to Early May) of the growing season due to poorly distributed rainfall patterns noted during the two consecutive cropping seasons. Thus, maize planted at the normal planting window particularly in 2018/2019 cropping season suffered from the drought spell in February and March, leading to suppressed growth and yield in all. Maize stover yield in 2018/2019 cropping season were relatively lower by 50% as compared with 2017/2018 cropping season, and this might have been associated with poor rainfall distribution similar to grain yield. The decline in grain and stover yields under tied ridges in year one and year two in the study aligns with arguments that tied ridges yield better for annual crops, under heavy rains planted early in the growing season (Jones & Clark, 1987). The low stover and grain yield at harvest, indicate severe drought stress during maize grain filling. For intercropping and ox-cultivation practices performed poor similarly to normal planting window, as this was caused by less precipitation after flowering ideally in the months of February to March (Fig. 3).

4.2.4 Effects of CSA practices, planting date and their interaction on maize nutrient uptake

Climate Smart Agriculture (CSA) practices improved uptake of nitrogen which is a critical nutrient for increased crop yield. In this study, soil moisture recorded under *chololo* pits CSA practices is highly associated with higher nitrogen nutrient uptake as similarly reported by Lipper *et al*. (2014). Soil moisture is greatly influencing nutrient uptake of any crops as it involves direct in microbial activities, transportation to the root and solution equilibrium (Lipper *et al.*, 2014). This supports the findings that *chololo* pits CSA practices makes available soil water potential at the soil root surface to regulate nutrient concentration for enhanced nutrient uptake. Similarly, the uptake of water and ions by a plant around root zone seems to concentration gradient in response to which water and ion flow from the root surface thus made it easier for Mg uptake by plant. Soil moisture in *chololo* and tied ridges at normal and late planting dates made nutrient uptake possible through diffusion process where dissolved $Mg+^2$ in soil solution. The site was found to be P limited as there was no significant differences across tested CSA practices as this would also have influenced photosynthesis and biomass production, however P was not statistically significant. The increase in P uptake by the plant for early planting date reflects 5.8% as compared with early planting date.

4.2.5 Economic benefits for CSA practices, planting date and their interaction

The costs of experimental materials such as fertilizer, seeds and pesticides used in this study as well as market selling prices of maize grains for 2017/2018 and 2018/2019 cropping season were recorded. In this study, it was found that *chololo* pits and tied ridges practices had the highest total variable costs (TVC), Margin Net Return (MNR) and Margin Rate of Return (MRR) as compared with intercropping and ox-cultivation practices. The results on TVC agrees with Mafongoya *et al*. (2016) that the demand for labour on farm management practices (farm equipment, land preparation, weeding and pesticides spray) increase costs of production. Despite the higher TVC in *chololo* pits and tied ridges CSA practices, its grain yield was higher which resulted into profit. Similarly, the MNR and MRR among these CSA practices and planting dates were higher as compared to intercropping and Ox-cultivation CSA practices. The initial costs of making *chololo* pits and tied ridges did not vary significantly with the costs for making tied ridges however time used and number of labour were considered in calculating its MNR and MRR. These results agree with CIMMYT (1988) that for any innovation to be sustainable must be economically profitable.

The results show that frequency of pesticides and insecticides application demanded labors and thus increased costs of production. This agrees with Muoni *et al*. (2013) that the trade-off due to additional costs on frequencies of pesticide applications may also be determined by farming practices and planting dates used. Mafongoya *et al*. (2016) reported that sometimes two or more pesticide chemicals must be combined to effectively control one pest or disease thus lead to extra costs. Time used for management of each practice varied quietly as *chololo* pits and tied ridges were reported to require more time for carrying out some activities in making ridges and basins.

The negative MNR reflects economic loss observed in the intercropping and ox-cultivation CSA practices similarly to normal planting dates. However, studies in Kenya argued that this type of losses can be partially compensated for, by adopting best practices like *chololo* pits and tied ridges which are resilient and economically sound in semi-arid areas (Mtei *et al*., 2013). The added advantage of maize stovers during harvesting is an advantage to be used as fodder crops or hay and act as a trade-off with the income from animal products (Kimaro *et al*., 2016). Agronomic assessment coupled with economic evaluations can help in defining production constraints and site-specific requirements thus providing the basis for targeting 'best-fit' specific technology options to specific site (socio-ecological niche) and defining extrapolation domains for technology adoption. Therefore, with improved extension efforts and market access coupled with site- specific targeting of technology options to crop productivity could be improved and ultimately the rural livelihood in Kongwa Tanzania.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The general aim of this study was to assess the resilience and economic benefits of the selected Climate Smart Agriculture (CSA) practices (ox-cultivation, tied ridges, *chololo* pits and intercropping) and three planting dates (early, normal and late). In Semi-arid areas Tanzania. The CSA practices/treatments were evaluated for their resilience on soil moisture retention, maize growth, yield and their economic benefits.

The result showed that CSA practices/treatments performed differently on soil moisture retention, growth and yield parameters (height of plants, stem girth of plants, above ground biomass dry weight of plants, leaf area index, photo-synthetically active radiation, number of cobs, grain and stover weight of maize crop) across the tested CSA practices/treatments.

This study revealed that *chololo* pits at early and tied ridges at late planting dates as CSA practices could be appropriate options among smallholder farmers to reduce the negative impacts of climate change, build climate resilient agricultural production systems, and harness the drought spells affecting crop production in semi-arid areas like Kongwa district.

Grain yield is the most valued component due to its food importance and selling for surplus. This study recommends *chololo* pits and tied ridges (at early and late planting date respectively) which demonstrated a higher grain yield and economic benefits as appropriate practise among vulnerable farmers to climate change in semi-arid conditions like Kongwa District in Tanzania.

Climate Smart Agriculture (CSA) practices showed a variation in costs and economic benefits, and their implementation requires appropriate investment decisions in both on-farm capital and for wider agricultural outreach programmes. Therefore, prioritization, evaluation and development of location specific portfolios of CSA practices linked to climatic risks are pre-requisite for developing scaling up/out pathway and CSA implementation plan. The rationale of understanding CSA practices and planting dates is also a critical issue to be considered in designing and deciding which CSA practices to suit sustainable and increased crop production under stressed areas like semi-arid conditions where the study was conducted.

5.2 Recommendations

The findings of this study revealed that CSA practices which consider appropriate CSA practices and planting dates on specific local settings can improve households' ability to adapt while delivering resilience environmental benefits in semi-arid areas which are vulnerable to climate change. The use of *chololo* pits at early and tied ridges at late maize-based framing systems in semi-arid areas should be promoted for improving maize production and building resilience. To provide a complete understanding of the influence of rainfall uncertainty on crop production, more studies are recommended to investigate the relationship between agro-climatic variability and suggested CSA practices in relation to economic implications in semi-arid conditions of Sub-Sahara Africa including Tanzania. However, the adoption of CSA practices will depend in part on the ability to make a business case for their benefits to the farmers, a cost benefit analysis of implementing CSA practices should be conducted.

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APPENDICES

Appendix 1: Experimental layout

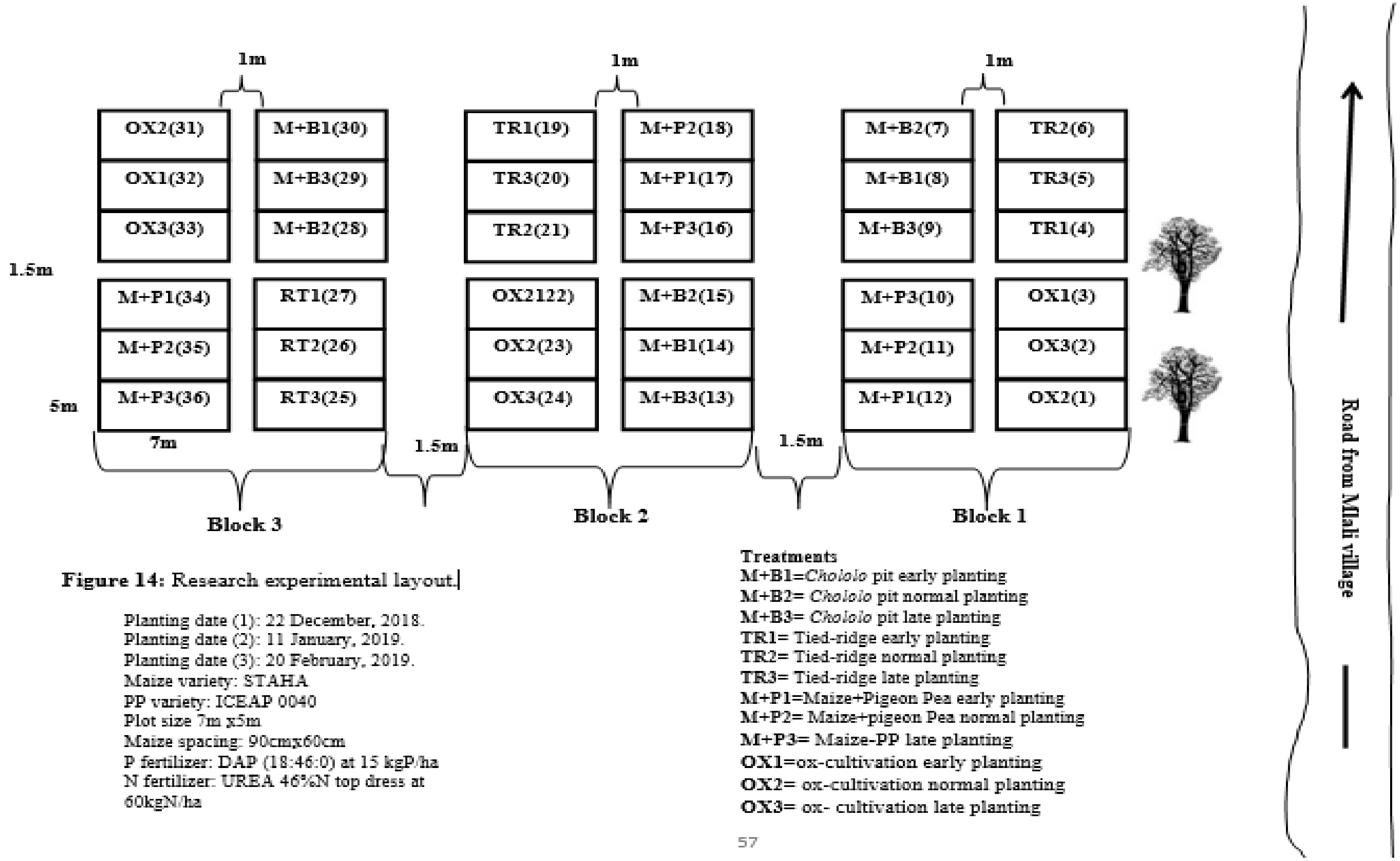

Figure 14: Research experimental layout.

Planting date (1): 22 December, 2018.
Planting date (2): 11 January, 2019.
Planting date (3): 20 February, 2019.
Maize variety: STAHA
PP variety: ICEAP 0040
Plot size 7m x5m
Maize spacing: 90cmx60cm
P fertilizer: DAP (18:46:0) at 15 kgP/ha
N fertilizer: UREA 46%N top dress at 60kgN/ha

Treatments
M+B1=*Chololo* pit early planting
M+B2= *Chololo* pit normal planting
M+B3= *Chololo* pit late planting
TR1= Tied-ridge early planting
TR2= Tied-ridge normal planting
TR3= Tied-ridge late planting
M+P1=Maize+Pigeon Pea early planting
M+P2= Maize+pigeon Pea normal planting
M+P3= Maize-PP late planting
OX1=ox-cultivation early planting
OX2= ox-cultivation normal planting
OX3= ox- cultivation late planting