EFFECTS OF *GRILICIDIA SEPIUM* INTERCROPPING, RAINWATER HARVESTING AND PLANTING TIMES ON MAIZE PERFORMANCE IN KONGWA DISTRICT, TANZANIA

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A DISSERTATION SUBMITED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN FORESTRY OF SOKOINE UNIVERSITY OF AGRICULTURE, MOROGORO, TANZANIA.

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ABSTRACT

This study assessed the effects of integrating *Gliricidia sepium,* rainwater harvesting known as chololo pits and planting times on soil moisture, maize growth and yield in Kongwa District, Dodoma, Tanzania. A factorial experiment was adopted to test the effects of planting times (Early, Normal and Late planting), and CSA practices (Maize monoculture, *Gliricida sepium* intercropping and intercropping with *G. sepium* and chololo pits. The planting times were Mid-November to Mid-December (Early), Mid-December to Mid-January (Normal) and Mid-January to Mid-February (Late). Results revealed that soil moisture content, maize growth and yield varied significantly between planting times and CSA practices. The *G. sepium*-chololo pits treatment increased soil moisture by 41% compared to 34% and 26% in the *G. sepium* and maize monoculture treatments, respectively. Overall, *G.sepium* intercropping alone increased maize grain yield by 23% relative to monoculture (2.6t/ha) due to improved soil moisture content and soil fertility. Maize grain yield was the highest (2.8-4.2t/ha) in the *G. sepium*-chololo pits treatment across all planting times, reflecting high resilience due to combined effects of improved soil fertility and soil moisture. At all planting times and CSA practices tested, the higher maize yields observed at maize planted Mid-December to Mid-January (Normal). This affirms the appropriate planting time of maize crops for Kongwa. This study demonstrated that the combined use of weather information on the appropriate planting time and CSA practice improves yield and build resilience in maize-based farming systems in semiarid areas.

DECLARATION

I, ABDALA S. LIINGILIE, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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DEDICATION

This work is dedicated to all key stakeholders working on agriculture and policy making all over the world.

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LIST OF ABBREVIATION AND SYMBOLS

%	Percent
ANOVA	Analysis of variance
C^0	Degree Celsius
Cm	Centimeter
CRBD	Completely Randomized Block Design
CSA	Climate Smart Agriculture
EU	European Union
FAO	Food and Agricultural Organization
g	Gramme
ha	Hectare
m	Meter
mm	Millimeter
SUA	Soikone University of Agriculture
t	Tonne
TMA	Tanzania Metrological Agency
USAID	United State Agency For International Development
USDA	United State Department of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Climate Smart Agriculture (CSA) practices together with the use of weather forecasted information in an integrated way can address the challenges of decreased maize production due to climatic rainfall variability in the semi-arid areas (Cairns *et al.,* 2013; La Rovere *et al.,* 2010; FAO 2013; Neufeldt *et al.,* 2013; Harvey *et al.,* 2014). CSA refers to land management practices that increase food security, the resilience/adaptive capacity of farmer households to climate variability and mitigate climate change by sequestering carbon in biomass and soils and/or reducing emissions when possible (FAO 2013), meanwhile Conservation agriculture (CA)-a combination of soil management practices that include reduced soil disturbance, permanent soil cover and crop rotation- is promoted extensively across sub-Saharan Africa and often labelled CSA (FAO 2013). CA and its derivatives that apply one or two of its three components have been found to address one or more of CSA's goals under certain conditions.

In the world, over 60% of maize is produced on rain-fed farming that cover 80% of the world's croplands. Similar pattern exists in Africa where, about 95% of food supplies come from rain-fed agriculture (Nellemann, 2009). According to Lobell et al. (2008) maize production in Southern Africa is projected to decrease to 70% of current production levels by 2030 due to production constraints including rainfall variability. Likewise, more than 80% of the farmers in Tanzania depend on climate sensitive rain-fed agriculture as source of livelihood (Kaliba *et al.,* 1998; EU, 2014).Similarly Ministry of agriculture livestock and fisheries of Tanzania has reported that the raising in mean annual temperature coupled with rainfall variability may reduce maize production by 13% in Tanzania. Maize is listed as the first ranked cereal in Tanzania which grows all over the country and plays major roles in the food security and income of the smallholder farmers (FAOSTAT 2013). Thus, promote CSA as a means for reducing vulnerability of maize to climatic rainfall variability is an important strategy to ensure sustainable maize production and enhance food security in the country.

Using climate resilient cropping systems and better management of the current climate variability can enhance farmer adaptation to the increasing threats of climate change (Cairns *et al.,* 2012). Potential adaptation options that would help to build resilience in maize production systems include better access and use of weather information coupled with the use of climate resilient technologies such as crops-leguminous trees intercropping (Cairns *et al.,* 2013). The application of weather forecasted information is an essential tool to provide early warning sign, which guides temporal sequence of adaptation measures, including the decision on the appropriate planting time. It is generally accepted that if farmers have readily access to weather forecast and use this information to make decisions on farm operations, it may significantly help to reduce climate-induced crop failure (TMA, 2016; Conway *et al.,* 2011; Coulibaly *et al.,* 2015). Likewise, the use of crop-tree intercropping in drylands can also provide resilience benefits to farmers (Kassam *et al.,* 2015). Some of these sustainable farming practices tested in semiarid central Tanzania include:

integrated land and water management practices, agroforestry practices (*G. sepium* or pigeon peas intercropping) and infiltration and tied-ridge have been used to ensure resilience to crops yield against drought related shock (Kimaro *et al*., 2016).

In Tanzania, agroforestry and conservation agriculture adopters do have higher adaptive capacity to climate change than non-agroforestry adopters due to diversified production options such as food, fodder and wood fuel, and reduced soil disturbance (Kimaro *et al*., 2016). The use of green manure such as *G. sepium* leaf and twigs biomass retention helps in changing soil physical properties such as hydraulic conductivity and bulk density which can increase water infiltration rates and soil moisture retention thereby helping crops to cope with intra-seasonal dry spells besides reducing soil erosion (Thierfelder *et al*., 2012 ; Kimaro *et al*., 2016).

Moreover it has been noted that Climate Smart Agriculture (CSA) practices with diverse or multi-species production systems on farms are more resilient than monoculture systems because of high ecological diversity and efficient use of growth resources through above and belowground niche separations (Thierfelder1 *et al.,* 2017). Additionally, in situ rainwater harvesting complemented with agroforestry or nutrient management practices have been reported to double crop yields in the Sahel drylands (Winterbottom *et al.,* 2013).Likewise the presence of coppicing stumps (e.g. *G.sepium*) can increase nutrients and moisture retention in the soil by maintaining a leaf canopy during the dry season. Also is building up soil organic matter to enhance the ability of the soil to capture rainfall, biological nitrogen fixation, and store and make it available to crops hence increased on farm production (Sileshi *et al*., 2007).

1.2 Problem statement and Justification

There is a lower maize yield ranging from 1-1.5 t/ha in semi-arid areas of Tanzania compared to national average yield of 4.5 t/ha (Masawe and Amuri, 2012; Meliyo *et al.,* 2014; Mkoma, 2015), that can attributed to various factors including low soil fertility and rainfall variability (Mkoma, 2015). Rainfall variability is the main weather element that constrains soil moisture availability in semi-arid areas thereby contributing to low maize production (Omondi *et al.,* 2014).

Several studies from dryland areas of Eastern and Southern Africa reported that on farm integration of trees/shrubs can address the soil moisture constraint through improved water harvesting, infiltration and soil moisture retention (Ngwira *et al.,* 2013). CSA practices which also involve planting at the appropriate time has more positive effects on maize grain yield (Nyamangara *et al.,* 2013) compared to conventional land preparation (Sileshi *et al.*,2007; Thierfelder *et al.*,2014). However, there is limited information on potentials of integrating rainwater harvesting technology known as Chololo pits, *G.sepium* intercropping and planting times for optimizing maize plants growth and yields in the same growing season in semi-arid areas (Thierfelder *et al.,* 2017). Therefore, this study assessed combined effects of CSA practices and planting times on maize plants growth and grain yields as a fundamental tool in making decision, and for promoting adoption of promising farming technologies along with appropriate planting time.

1.3 Objectives

1.3.1 Overall objective

The overall objective of this study was to assess the appropriate farming practice and planting time that optimize maize growth and yield in semiarid zone.

1.3.2 Specific objective

The specific objectives are;

i. To assess the effects of *G. sepium* intercropping with and without chololo pits on soil moisture.

ii. To assess the effects of planting times and *G. sepium* intercropping with and without chololo pits on maize plants growth.

iii. To assess the effects of planting times and *G. sepium* intercropping with and without chololo pits on maize yields.

1.4 Hypothesis

i. Integration of *G. sepium* and chololo pits has positive effects on soil moisture content.

ii. Combinations of planting times and chololo pits with *G. sepium* has positive effect on maize plants growth

iii. Combinations of planting times and chololo pits with *G. sepium* have positive effect on maize yields.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The use of weather information to determine planting time

Shifting rainfall pattern due to climate change leads more vulnerable to maize production. Recently farmers have reported that, rainfall season is less predictable, starting later, and finishing earlier, which affecting maize production, hence food shortage or famine (EU, 2014). Therefore, to initiate the appropriate adaptation strategies general awareness including the use of weather information together with appropriate communication channels used is an essential (Coulibaly *et al*., 2015).

The use of weather information in deciding the appropriate time of planting coupled with best bet farming technologies can plays a great role in maximizing maize production yield (Kirui *et al.,* 2010). The implications of weather information is an essential tool for providing early warning sign, adaptation measures including adjustments to planting dates as the adaptation measure to shifted rainfall (Kirui *et al.,* 2010; Osbahr *et al*., 2011). Previous studies have suggested that average maize production could be increased if farmers use climate information (Kirui *et al.,* 2010, Hansen and Indeje 2004).

Tanzania has a Metrological Agency (TMA) which is responsible for forecasting and releasing of climate information in each growing season to farmers on expected rain onsets, amount of rainfall and recommendation of the right time for planting in order to cope with rainfall patterns (TMA, 2016). However, there are no empirical evidence in terms of extent of contribution to maize production that farmers will gain or lose if don't use the TMA weather information on cropping season (TMA, 2016).

2.2 Role of Nitrogen in maize production

The additional of Nitrogen element in the soils maximize maize production (Morris *et al.,* 2007; Kimaro *et al*., 2009). With N fertilizers, crop yields can often be doubled or even tripled (FAO, 2013). However, in spite of their increased application over the years, per hectare yield of crops still remain low in Tanzania compared to other developed countries (Ahmed *et al*., 2012). The available data show that the average crop yield per hectare in the country has declined from 1.4 t/ha in 2007/08 production season to 1.2 t/ha in 2009/10 production season (FAO, 2011). Inadequate knowledge on efficient use of fertilizer is among the reasons which lead to low maize production in Tanzania. Low yield obtain by farmers despite use of fertilizer disappoints them and quit from chemical fertilizer application.

2.3 Effect of *G.sepium* intercropping on Surface soil chemical properties

Gliricidia pruning's influences positive change of the soil chemical properties on farm. As observed by Akinnifes *et al*. 2006 soil fertility levels were significantly higher under gliricidia/maize intercropping than sole maize ($p< 0.05$**).** The mean soil organic C, extractable P, exchangeable Mg and K were maintained at significantly higher levels with *Gliricidia* pruning's than in plots without pruning's compared to the original soil pH (Table 1).

The levels of soil extractable P, exchangeable Mg and K at the end of trial in 2000/01 were significantly higher than at initial plot establishment. There was no evidence of a significant interaction between fertilizer level and pruning applications.

The higher nutrient status under the gliricidia/maize system compared to the sole maize cropping is evidence that organic inputs from tree leaf and twings prunings have beneficial effects on soil chemical properties. Several other soil fertility trials in Africa have indicated beneficial effects of organic inputs on soil fertility replenishment (Kimaro *et al*., 2016). The larger amounts of exchangeable Ca, Mg and K in the topsoil in gliricidia/maize than sole maize plots are evidence of recycling of nutrients from depth by the deep-rooted trees.

Table 1: Surface (0–20 cm) soil chemical characteristics and changes in soil nutrient status of the baseline values (at field establishment) compared to status after nine years of continuous cropping under a gliricidia-maize intercropping system in Makoka

Production system†	pH (H_2O)	Organic C ($g\ kg^{-1}$)	Extractable P ($mg\ kg^{-1}$)	Exchangeable cations ($cmol_c\ kg^{-1}$) Ca	Mg	K
1991/92 season						
(Baseline‡)	5.9 (0.17)	8.8 (0.49)	26 (3.76)	4.4 (0.12)	1.6 (0.21)	0.30 (0.05)
2000/01 Season						
Sole maize + 0 kg N ha^{-1}	5.9	8.2	24	3.6	1.0	0.13
Sole maize + 23 kg N ha^{-1}	5.8	7.6	20	4.1	0.8	0.11
Sole maize + 46 kg N ha^{-1}	5.8	7.0	21	4.0	1.1	0.16
Mean	5.8	7.6	22	3.9	1.0	0.13
Gliricidia + 0 kg N ha^{-1}	6.0	9.1	36	4.5	2.4	0.54
Gliricidia + 23 kg N ha^{-1}	6.1	8.9	31	4.3	2.3	0.37
Gliricidia + 46 kg N ha^{-1}	6.1	8.7	33	4.3	2.1	0.52
Mean	6.1	8.9	33	4.4	2.3	0.48
LSD (0.05)¶						
Production system	ns§	0.81	6.45	Ns	0.37	0.13
N fertilizer rate	ns	Ns	Ns	Ns	0.45	0.16
Prod. Syst. × N Fert. Rate	ns	Ns	Ns	Ns	Ns	ns
C.V. (%)	12.6	9.3	21.6	22.4	20.3	25.6

†The inorganic fertilizer was all applied at once four weeks after planting.

§Not significant.

¶Least significant difference.

‡Baseline indicates the initial soil properties at the year of plot establishment in 1992/93 season (soil chemical properties data represents the bulked sample across three replicates). Figures in parenthesis represent the standard errors.

2.4 Effect of *Gliricidia* pruning's and fertilizer on maize grain yield

Fertilizer tree-intercropped farming including *G.sepium* practiced across sub-Saharan Africa has been shown to increase maize yield (Sileshi *et al.,* 2012). The *G. sepium* shrub plays a special role in the intercropping system through its ability to thrive in N-deficient soils, reduce soil erosion, improve water and nutrient cycling and increase both soil organic carbon and the activities and abundance of beneficial soil organisms (Barrios *et al*., 2012).

The characteristic of rapid decomposition of *G sepium* leaves and twigs after pruning and mulching increases in growth and yields of the crops. Frequent pruning, stimulates N transfer to intercrops via fine root and nodule turnover and root exudations and *G. sepium* can fix nitrogen up to 166 kg/ha after 9 months and can supply green manure of 46 kg N/ha in each season (Kimaro *et al*., 2016). The consistently higher grain yields in conservation agriculture and trees can be driven more by nutrient inputs not only improve soil moisture and root proliferations of the double digging. These results are consistent with the argument that nutrient are critical for high productivity in maize systems of sub-Saharan Africa (Sommer *et al*., 2014; Vanlauwe *et al*., 2014).

The studies conducted in various areas of Southern Africa have shown *Gliricidia* pruning's have positive influences on maize grain yields (Thierfelder *et al*., 2017). Table 2 shows the long-term effects of gliricidia as an N source on maize yields, with and without mineral N supplements from 1992/93 to 2001/02. The biomass nutrient yield data showed that per year the trees have the potential to supply nutrients at levels of up to 298 kg N/ha, 21 kg P/ha and 170 kg K/ha (Akinnifes *et al.*, 2006).

The general observation had revealed that without *G.sepium* and fertilizer plots, the maize yield in sole maize cropping declined steadily from 1994 kg/ha in the first cropping season (1992/93) to 529 kg/ha in the fifth cropping season (1996/97). The lowest maize yield from unfertilized sole maize, obtained in 1996/97, coincided with excessive rainfall and associated damage due to lodging. The effects of this damage were not as pronounced in the gliricidia/maize intercropping systems which produced a yield of 3356 kg/ha. The largest maize yield from the unfertilized gliricidia plot was harvested in the first cropping season (1995/96) 5302 kg/ha. Yield increases over the unfertilized sole maize ranged from 100% in 1994/95 to > 500% in 1996/97.

Maize yields in the gliricidia/maize treatments were greater than in the sole maize plots in all years ($p < 0.001$), except in the first cropping season (1992/93), when there was 17% yield reduction in gliricidia plots ($p < 0.05$). The generally low yield in the sole maize plot was partly offset by the fertilizer N applied at the rate of 46 kg/ha. The greatest N response under gliricidia/maize system was also observed during the first maize season in 1992/93. Afterwards, maize yields from fertilized (half-dose) sole maize plots were similar to those from unfertilized gliricidia plots. However, the effect of fertilizer rate was highly significant on maize grain yield in all years ($p < 0.001$), except 2000/01.

The positive effect of gliricidia application was very highly significant ($p < 0.001$) in all years except for the first cropping season ($p < 0.05$). This coincided with tree initial establishment phase. In the second cropping season, maize yields in the gliricidia/maize system were double those of the control plot without fertilizer. In general, the long-term average maize yield was maintained at 3.8 t/ha under gliricidia/maize intercropping without chemical fertilizer inputs, compared to 1.2 t/ha from unfertilized sole maize during the 10 cropping seasons (Table 2). The highest maize yield was obtained in 1994/95 under the gliricidia/maize system and ranged from 5.3 t/ha without chemical fertilizer input to 7.1 t/ha with a quarter N and 7.5 t/ha with half the recommended N rates (Table 2). This demonstrates the potential of the gliricidia/maize system and synergy with small fertilizer N doses in favorable years.

Table 2: **Maize grain yield (kg/ha) in a maize-*Gliricidia* intercropping system during ten consecutive cropping seasons (1992/93 to 2000/01)**

Production system	N Fertilizer rate (%)†	1992/93‡	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02
Sole maize (no trees)	0	1994	1501	1490	1200	529	1073	1015	804	857	1000
Gliricidia + maize	0	1657	3922	2984	5302	3356	4322	4487	2309	5059	4150
	Mean	1825	2712	2237	3251	1943	2698	2751	1557	2958	2575
Sole maize (no trees)	25	3418	2111	3108	3917	1987	2953	2646	1708	2640	2890
Gliricidia + maize	25	2982	4446	4092	7117	4160	5997	5926	2947	5830	5290
	Mean	3200	3279	3600	5517	3074	4475	4286	2328	4235	4090
Sole maize (no trees)	50	4147	3155	3320	4750	1931	4000	3844	2076	3018	3620
Gliricidia + maize	50	4013	4545	3730	7523	4469	5815	6455	3519	6344	5120
	Mean	4080	3850	3525	6137	3200	4908	5150	2798	4681	4370
LSD(0.05):											
Prod. syst.		198	169	132	172	232	123	212	166	321	530
N fert. Rate		242	207	161	211	285	151	248	204	393	649
Prod. syst. × N		ns	293	228	232	ns§	214	350	ns	ns	ns
fert. rate C.V. (%)		11.7	11.8	11.9	5.98	15.3	12.5	6.58	15.8	18.9	13.7

‡The tree establishment was done in December 1991 and first maize crop was planted in 1992/93 cropping season, after tree was about one year old. First tree pruning done in September 1992 and incorporated.

†Inorganic fertilizer N levels (0, 25 and 50% of recommended fertilizer rates correspond to 0, 23 and 46 kg N/ha respectively), all applied at once four weeks after planting.

§ns: not significant.

Furthermore in Tanzania, *G.sepium* intercropping has found to increase maize grain yield due to high soil moisture retention and other biophysical activities on farm (Kimaro *et al*. 2016). As found in Morogoro region the intercropping of *G.sepium* improved maize grain yield compared to the conventional cultivation using a hand hoe. Significant effects, leguminous tree (CAWT) integration as noted for the long rain growing seasons in 2013 (p = 0.016) and 2014 (p = 0.013) and the short rain growing season in 2013 (p = 0.002). Corresponding maize grain yields for Conservation Agriculture (CA) and Conservation Agriculture with Trees (CAWT) in these seasons were 2.1 and 2.2, 2.8 and 3.2, and 2.1 and 2.3 (t/ha) respectively.

Moreover, in central Mozambique, intercropped maize with pigeonpea (*Cajanus cajan)* showed huge increases in Soil Organic Carbon (Rusinamhodzi *et al*, 2011). Similar results were observed by Ngwira *et al.* (2012) from Malawi, where they observed a 76% increase in Soil Organic matter and crops yield when maize was intercropped with legumes. Likewise in Zimbabwe agroforestry practices have been found to improve water harvesting and increase the soil moisture content and higher maize yields compared to conventional farming practices (Sileshi *et al*., 2007; Thierfelder *et al.,* 2014).

However, trees if not well managed can also compete with crops for water and nutrients and reduce the land area available for crops. Therefore, the net effect of agroforestry on crop yields over time will depend on attributes and interactions of the trees, crops, soil, climate and management (Thierfelder *et al*., 2017).

2.5 The role of basin planting practices on soil moisture and crop production

Soil moisture availability for plant growth is a major constraint to attain sustainable crop production, particularly in Sub-Saharan African countries where the majority of the populations depend on climate-sensitive agricultural production (Nellemann, 2009). Basin planting practices with trees practices can increase soil moisture retention and rain use efficiency to crops than conventional farming practices as the result of improved maize grain yield (Kimaro *et al*., 2016).

Generally, Basins planting performed better convention farming practices. According to Nyamagana *et al.* in 2013, found that weighted mean difference was significant by 0.241 t/ha in basin planting, compared with 0.094 t/ha of conventional practices, which was not significant (Table 3). The effect of basins was significantly different ($p < 0.001$) from conventional in 64% of the paired comparisons. In contrast, the effect of the ripper was significantly different from convention in only 8% of the paired comparisons (Nyamagana *et al.*, 2013).

Table 3: **Weighted mean difference for maize yield (t/ha) under conservation agriculture for experiments conducted in Zimbabwe from 2004 to 2010 and distribution of observed effects relative to maize grain yield under conventional tillage.**

Treatment (n)	Weighted mean difference (t/ha)	Positive (%)	Neutral (%)	Negative (%)	P
Planting basins (81)	0.241	59	1	40	0.0001∗∗∗
Ripper (44)	0.094	64	0	36	0.2039NS
Planting basins on farm (34)	0.342	71	3	26	0.0001∗∗∗
Planting basins on station (47)	0.168	51	0	49	0.0214∗
Ripper on station (44)	0.112	67	0	33	0.1850NS
Soil type					
Planting basins clay (34)	0.194	56	0	44	0.0256
Ripper clay (30)	0.051	60	0	40	0.6372NS
Planting basin sand (17)	0.365	65	0	35	0.0055∗∗
Ripper sand (14)	0.184	71	0	29	0.0080∗∗
Rainfall					
Planting basins (rainfall 320–500 mm) (45)	0.151	53	2	45	0.0183
Ripper rainfall (rainfall 320–500 mm) (34)	0.110	65	0	35	0.0921NS
Planting basins (rainfall 500–830 mm) (25)	0.095	56	0	44	0.9290NS
Ripper (rainfall 500–830 mm) (9)	0.105	67	0	33	0.8028NS
Planting basin (well-distributed rain) (19)	0.463	68	0	32	0.0178∗
Planting basin (poorly distributed rain) (60)	0.141	55	2	43	0.0074∗∗
Ripper (well-distributed rain) (11)	0.026	55	0	45	0.9319NS
Ripper (poorly distributed rain) (33)	0.116	67	0	33	0.0837NS
Fertility					
Planting basins (0 kg N ha−1) (11)	0.048	64	0	36	0.3511NS
Planting basins (10–30 kg N ha−1) (48)	0.265	54	2	44	0.0012∗
Ripper (10–30 kg N ha−1) (39)	0.122	67	0	33	0.1607NS
CA (planting basins + no manure) (12)	0.043	73	0	27	0.4458NS
Planting basins + manure (49)	0.159	53	0	47	0.0276∗
Ripper + manure (42)	0.115	67	0	33	0.1437NS
Mulch					
Planting basins + no mulch (12)	0.156	58	0	42	0.1232NS
Planting basins + mulch (24)	0.087	50	0	50	0.4516NS
Ripper + no mulch (11)	0.191	64	0	36	0.0581NS
Ripper + mulch (24)	0.022	67	0	33	0.8516NS
Mean	0.152	61.4	0.37	38	

NS: non-significant; * significant at 5%; ** significant at 1% and *** significant at <1%.

For basins planting practice, the effects may be more apparent in the initial phases of CA implementation because of early-season water harvesting, the facilitation of early planting (especially in the smallholder farming systems) and the concentration of soil fertility amendments, or some combination (Nyengerai, 2010) further influenced by field and soil type (Ncube, *et al.*, 2009; Zingore *et al.*, 2007).

In semiarid areas of Tanzania rainfall variability affect maize crop negatively and is predicted to be further declined due to unpredictable rainfall and shortens the growing season (EU, 2014). For example, in the central region of Dodoma there is low average maize production and is predicted to 33%, with largest decreases up to 84 % in 2040 (Vrieling *et al.*, 2013). It estimated climate rainfall variability affects nearly 80% of the population who directly or indirectly depend on maize rain fed agriculture (Nelson *et al.*, 2014).

Shifting of rainfall patterns will therefore inevitably affect the economy and livelihood of people. Concomitantly, the introduction of resilient farming practices that mitigate climate change effects could be a plausible strategy for food security and income of people.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study Area

A study was conducted at Laikala village in Kongwa district, which located at latitude 5.47^o and 6.26^o S and longitude 36.15^o and 37.08^o E in Dodoma Region (Fig. 4). The district is characterized by medium altitude plains with some hill ranges; mainly medium textured soils with low to moderate fertility (Meliyo *et al.,* 2014), Also characterized by undulating to rolling plains and plateaus with elevation that range between 500 –1200 m.a.s.l. Soil of the experimental field was sandy loam in texture, low in organic C (0.32%), low in available nitrogen (0.05%) and low in available phosphorus (5.16 cmol/kg) and potassium (0.51 cmol/kg) contents **(**Table 4). Soil reaction was neutral (pH 6.3) (Meliyo *et al.,* 2014; Mkoma, 2015).

Table 4: **Soil chemical and physical properties of the experimental site at Laikala village**

Soil Properties	Values
pH (H20)	6.3
Cacl2)	1.17
% C	0.32
% N	0.05
K cmol/kg	0.51
Na cmol/kg	0.46
Ca cmol/kg	1.17
Mg cmol/kg	0.36
CEC cmol/kg	3.08
P cmol/kg	5.16
Sand (%)	78
Silt (%)	6
Clay (%)	16
Textural Class	Sandy loam

Source: Mkoma (2015)

The amount of rainfall received varied unpredictably in terms of the onset and distribution over time (Mongi *et al.,* 2010). Large part of the district is semi-arid areas and has growing period of 75 – 179 days and the average rainfall ranges from 200 to 800 mm (TMA, 2016). The average annual rainfall in Dodoma region is 550 mm. However, seasonal rainfall distributions very sporadic with 48% of the rains falling towards the end of the growing season giving little advantage to maize growth and yield (Kimaro *et al.*, 2009). According to TMA, rainfall data of 30 years between growing seasons of 1981/1982 to 2009/2010 show that the month of January is the successful planting window with low risk of crop failure. Normally short rain seasons in Kongwa district start from the third week of November to the first week of January and on average, the seasons start in the third week of December. Occasionally, the rainy season may start earlier or get delayed to outside the normal range, for example in the years 1997/98 and 2003/04 the rainy seasons was delayed Fig. 2. Likewise, the ends of the long rainy season in Kongwa District vary from season to season, normally ends in the first or second week of April. Occasionally, the rainy seasons may end earlier or get delayed to outside the normal range to the third week of April or first week of May Fig. 3.

For growing season 2017/18, total rainfall amount of the experimental field recorded was 494mm which was below average and lowest in February as this month received only 25mm of precipitation after a rainfall event in late February (Fig. 1).

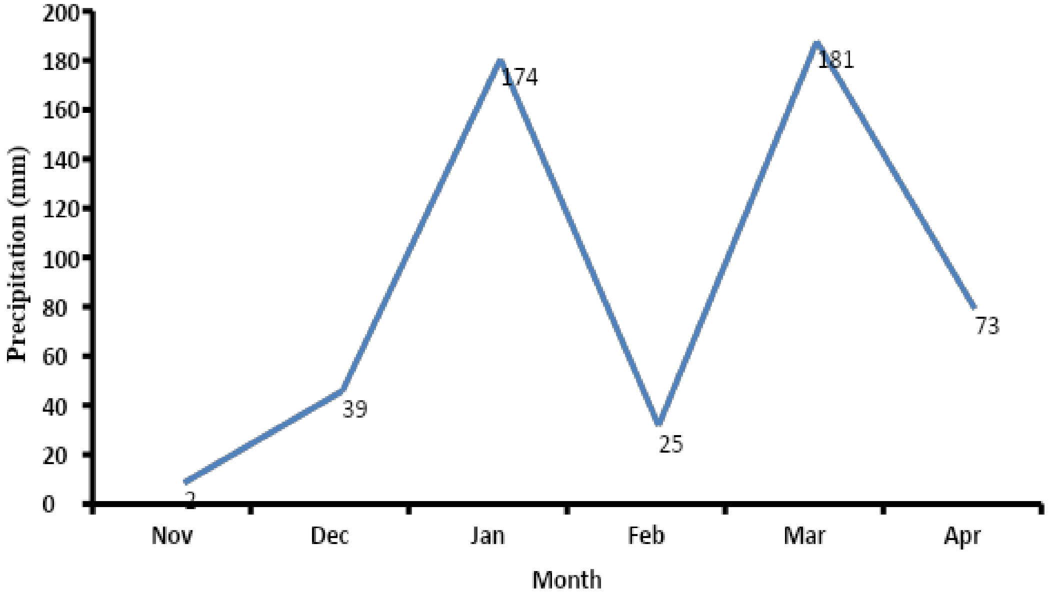

Figure 1: Amount of precipitation at Laikala site in the growing of 2017/2018

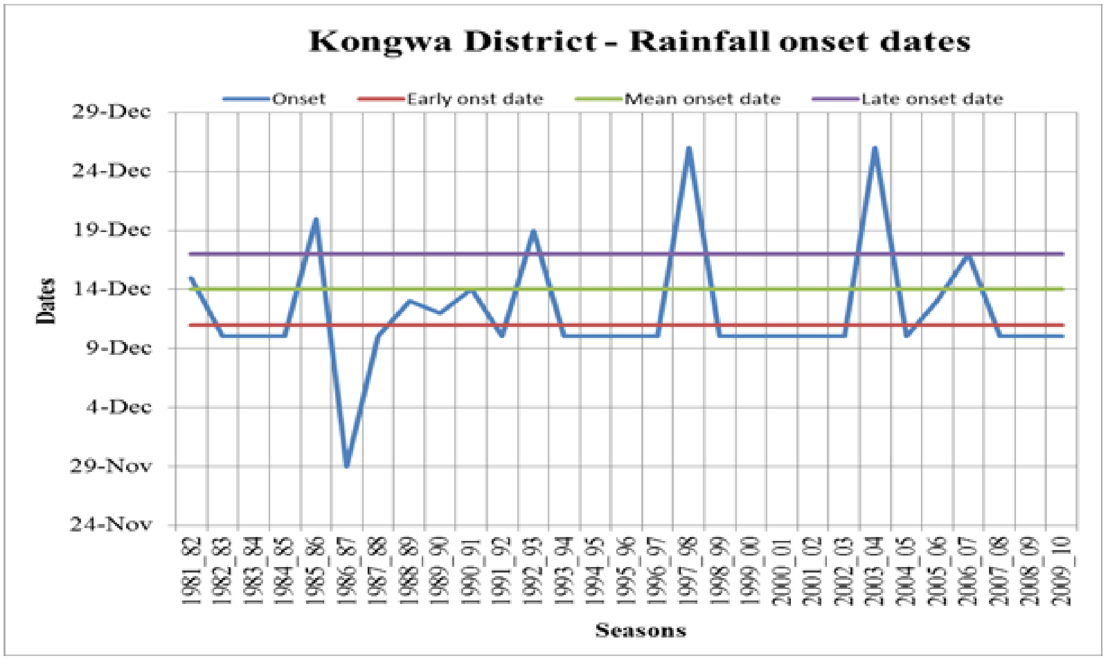

Figure 2: Dates for the beginning (onset) of the short rainfall seasons in Kongwa District from the periods of 1981/1982 to 2009/2010

Source: (TMA, 2017)

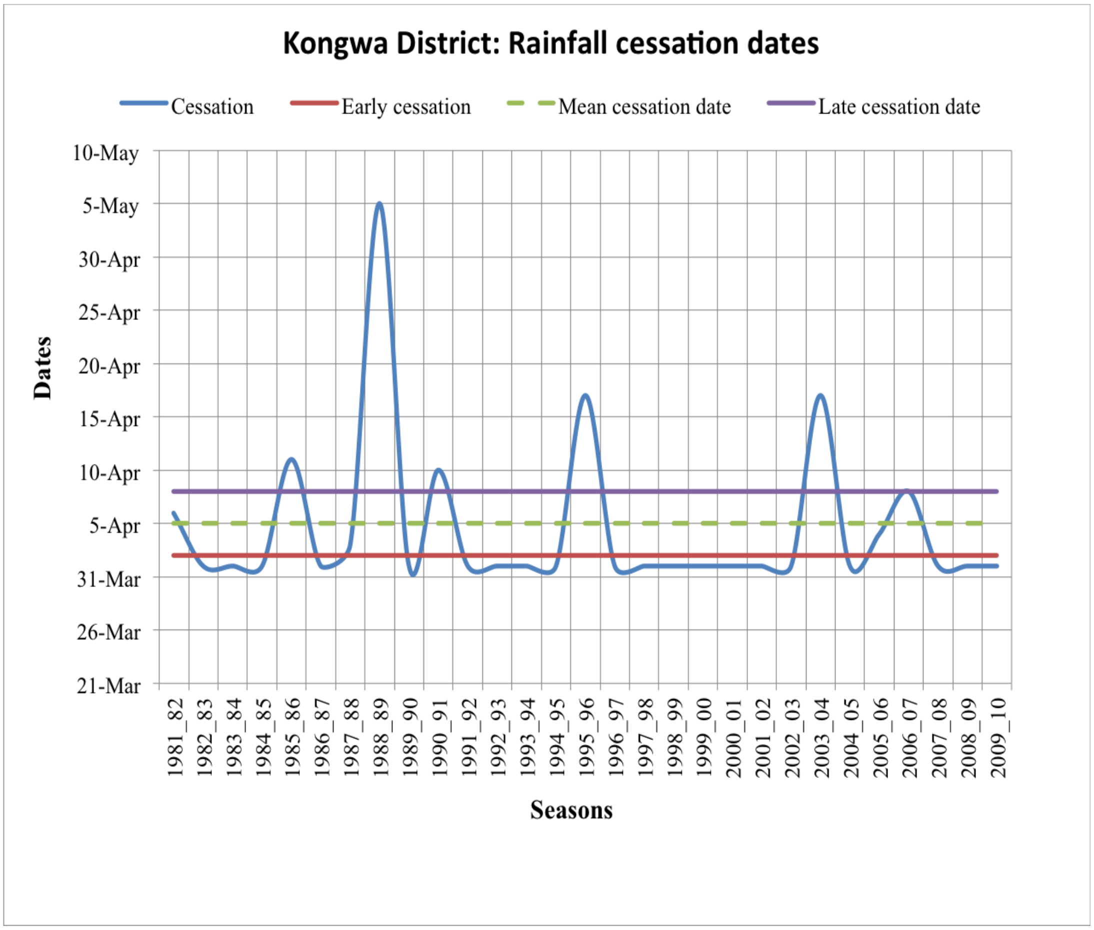

Figure 3: Dates for the end of the long rainy seasons in Kongwa District from the periods of 1981/1982 to 2009/2010.

Source: TMA, (2017)

Other crops grown in semi-arid zone are sorghum, maize, cassava, Sweet potatoes, finger millet, pigeonpea, lablab, groundnut, Bambara nuts, simsim, soybean, sunflower, jatropha, bean, cowpea and castor.

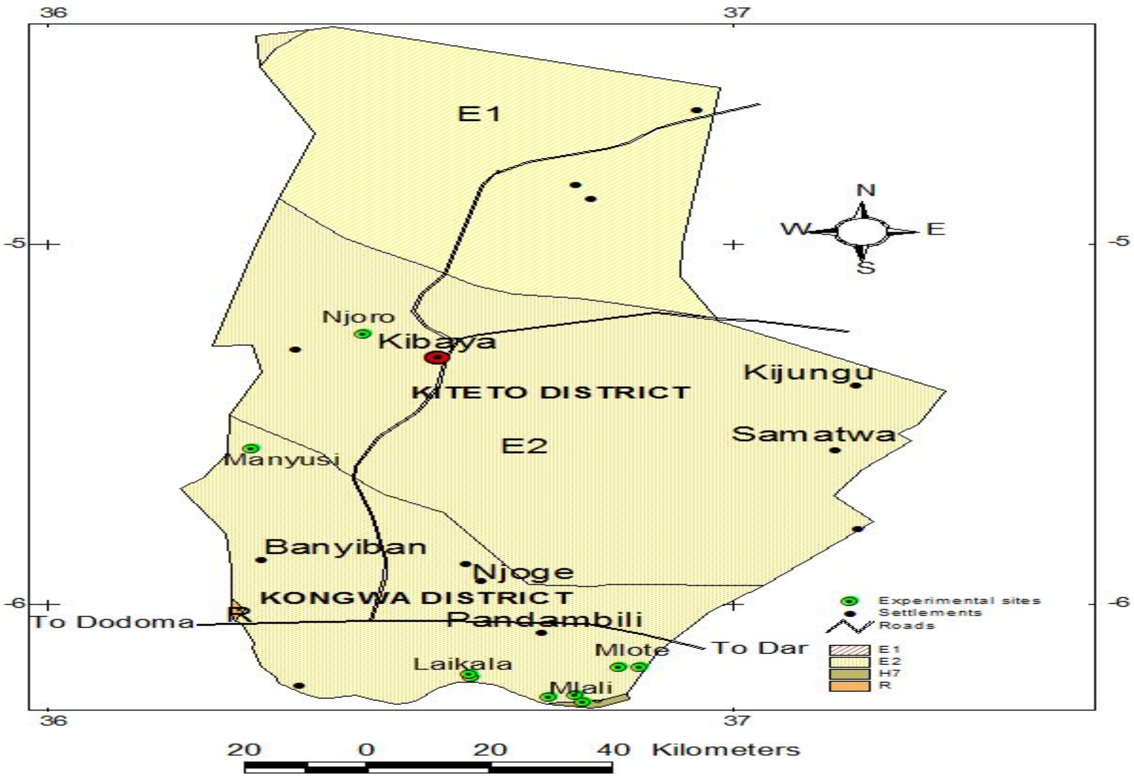

Figure 4: Map of Kongwa District showing experimental site

3.2 Methods

3.2.1 Experimental design, treatments and management

A factorial experiment laid out in a Randomized Completely Block Design (RCBD) with 3×3 factorial arrangement with three replications. The treatment factors were: (i) production system (sole maize, maize *Gliricidia sepium* intercropping with or without with chololo pits; (ii) Planting times which were divided into three times of maize planting (Early, normal and late planting). The planting times categorization (Early, normal and late planting) was based on information from previous studies (EU, 2014) and according to the Tanzania Metrological Agency (TMA), using rainfall seasons data of the past 30 years for Kongwa district as presented in Figures 2 and 3.

Therefore, based on rainfall information, early planting time was determined to range from Mid-November to Mid-December, normal planting from Mid-December to Mid-January and late plating from Mid-January to Mid-February.

A plot size of 7m x 5m was adopted and separated by the unplanted buffer strips of 1m. The distance between and within blocks was 1.5m and 1m respectively, and the treatments were allocated at random manner within each block. *G. sepium* have 3-4 years and planted at a spacing of 3 x 3m (inter- and intra-row spacing and intercropping planted at ratio of three rows of maize and one rows of *G.sepium* (3:1). 3-4 seeds of Maize (Variety Meru 513) by using dibbling method were sown per hill at a spacing of 60 cm within rows and 90 cm between rows of maize for all plots and every tested treatment.

3.2.2 Management of the Experiment

Prior to planting, the site was prepared according to tested land management options. Before the rainfall and growing season started, rectangular basins of length 30cm, depth 20cm and width 15cm famous known as chololo pits were dug. The chololo pits made at inter and intra row spacing of 90 x 60cm respectively (plate 1).

Plate 1: Rectangular chololo pits of depth 20cm and width 15cm made at Laikala illage site (Credit photo: Abdala Liingilie, 2018).

To ensure site homogeneity in all plots, basal application of cow manure (961g/hill or 15t/ha) and NAFAKA Plus (700 g/hill or 15 kg P/ha) were applied by localization method on the hill and Chololo pits to supply for N, P and other elements which are known to be deficient in soils in Dodoma (Kimaro *et al.*, 2009; Mkoma, 2015).

Plate 2: Organic manure and inorganic fertilizers applied during planting at Laikala village site (Credit photo: Abdala Liingilie, 2018).

For the *G. sepium* treatments the prunings from pruning *Gliricidia sepium* leaves and twigs were added 2 times direct incorporated into the soil. A first pruning of G. sepium was done during maize planting and second pruning at vegetative stage of maize growth which released about 2.3t/ha and 5.3t/ha of green manure respectively. 3-4 maize seed were sown and after germination, thinning was carried out in all plots. Two maize plants were left per hill to control maize plants stocking based on the spacing used. Also pesticides were applied for pest-insect diseases management. Karate and Sapa Carbaryl 5% dust was used to control the spread of the insect-pest and diseases to other plants. Karate contained 50 grams lambada cyhalothrine per litre and 250mls used. And Sapa Carbaryl 5% dust used to control infestation of stalk borers, armyworms and foliar feeding beetles. Weeding was carried out 3 times by using man hand hoe.

3.2.3 Data collection

3.2.3.1 Rainfall information

The daily rainfall was recorded within 24 hours in the morning at 09:00 am and same time the following day. The rainfall data were recorded from a rain gauge, installed on a post and placed on the clear ground to avoid errors associated with leaf obstructions.

3.2.3.2 Soil Moisture

Soil moisture was monitored since crop emergence to the time of harvesting (Karuma *et al.,* 2014). To monitor soil moisture regime across the growing season as well as determination of moisture retention capacity of each farming technology established soil samples were collected in each month of maize growth stages. In each plot, one soil sample of 100-200g was collected at random from three points per farming practice tested. The soil samples were taken at the depth of 0 - 20 cm and mixed thoroughly and were taken to the laboratory for soil moisture analysis by the gravimetric method.

3.2.3.3 Leaf Area Index (LAI) and maize biomass

In each treatment, the Leaf Area Index (LAI) of maize plants were recorded at full grain filled stage (11 weeks since maize plant planted). The maize plants growths were recorded directly by using AccuPAR PAR/LAI Ceptometer Model LP-80 (plate 3). At least 4 readings per plots were recorded randomly based on weather conditions and crop uniformity (Decagon Devices, 2015).

Plate 3: Leaf Area Index (LAI) recorded directly by using an AccuPAR PAR/LAI Ceptometer Model LP-80 device (Credit photo: Elvis Jonas, 2018).

For determination of dry matter accumulation (DMA) of maize plants at full grain filled stage (R3) and ready for roasting and eating (75 days after planting) in each treatment combination, five plants were sampled from the maize rows and the whole fresh weights were recorded and one maize plant sub-sampled from the five, weighed and delivered to laboratory (Ghosh *et al.*,2017), thereafter one sampled maize plant was placed in oven and dried at 70 ºC till constant weight was obtained for determination of whole dry matter yield per each treatment.

3.2.3.4 Maize grain

Maize grain yields at physiological maturity were collected from the inner plot area of 5 m x 3.6 m and sub-samples (approx. 200g) taken to the laboratory and oven dried at 70 ºC. Thereafter, dry maize grain yields results from laboratory were extrapolated to a hectare (ha) based on the net plot area harvested.

3.2.4 Data analysis

Rainfall data was subjected to descriptive statistics. Soil, maize growth and yield data were subjected to two-way Analysis of Variance (ANOVA) at 5% significance level done using Turkey test to evaluate mean separation effects between tested treatments. Microsoft Excel office and Gen STAT Discovery Inc. Version 15th (2012) statistical tools were used to organize and analyze data.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of *G. sepium* intercropping and chololo pits on soil moisture

Results of ANOVA (Fig. 5 and Appendix 1) had shown that the average amount of soil moisture content in chololo pits-*G.sepium* and maize-*G.sepium* were significantly (p=0.001) higher compared to maize monoculture. In all farming practices tested, high mean percentage of soil moisture content was observed in the chololo pits-*Gliricidia* (6.1 %), followed by Maize- *G.sepium* intercropping (5.1 %) and maize monoculture (3.9%) (Fig.5). In chololo-pits-*G.sepium* soil moisture was relatively higher by 41% compared to 34% and 26% of maize-*G.sepium* and monoculture respectively.

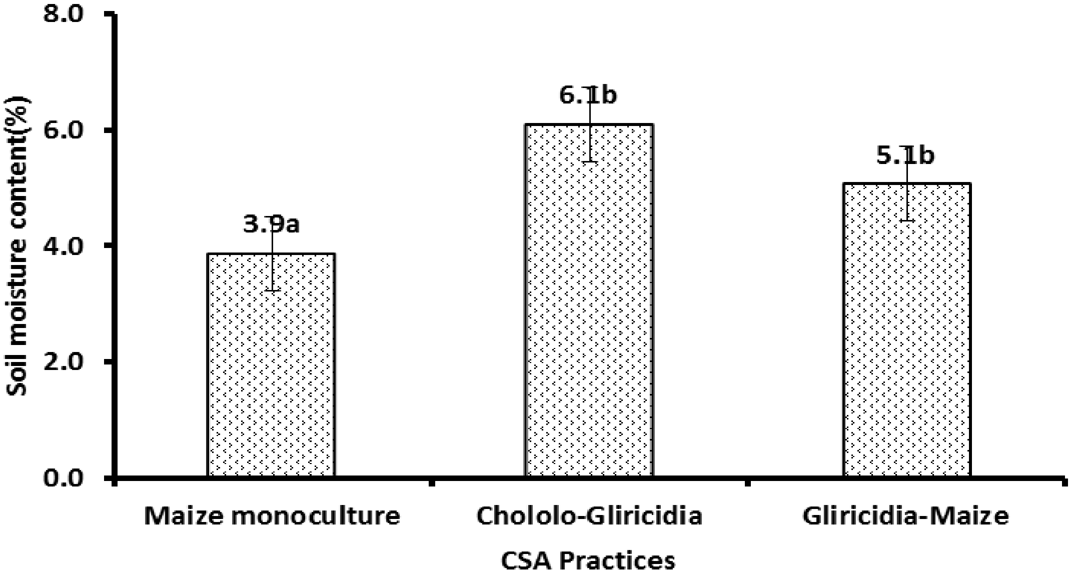

Figure 5: The effects of CSA practices on soil moisture at Laikala Village, Kongwa District, Dodoma. Means bearing different letter(s) do differ significantly at P≤0.05 according to Tukey's test.

Across the months, the highest soil moisture was observed in April (SMC=11.5%), and January (SMC=7.4%), and lowest in early and late February (SMC=1.9% and SMC =1.6% respectively (Fig. 6). Similarly, the mean rainfall was also the lowest in February as this month received only 25mm of precipitation after a rainfall event in late February (Fig. 1). The significant higher observed soil water content in the *G.sepium* -Chololo pits suggests that the combination of *G.sepium* and chololo pits have higher capacity of soil moisture storage than maize monoculture.

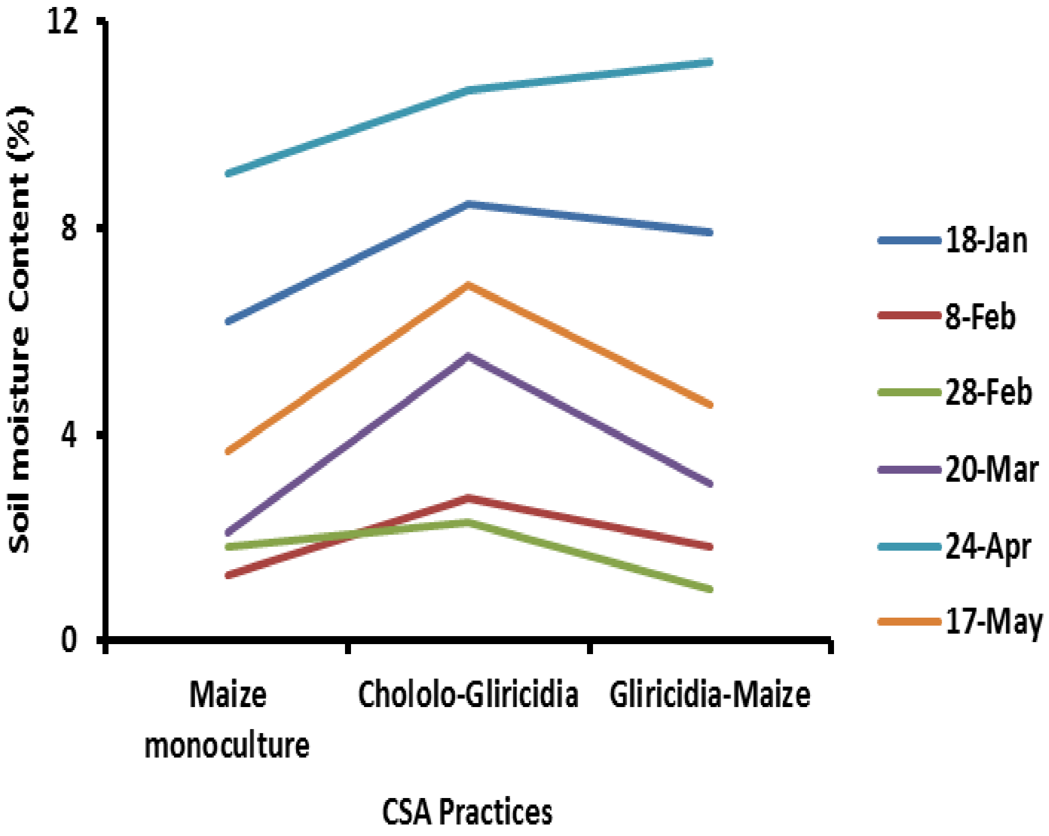

Figure 6: The effects of farming practices on soil moisture variability across the growing season.

4.2 Maize plant growth

General growth performance of maize plants varied significantly (p=0.001) between treatments (Appendix 2). Leaf Area Index (LAI) for various treatments ranged from 1.4 to 2.9 (Fig. 7). The high value recorded were from early, normal and late maize planted under *G.sepium*-chololo pits and maize-*G.sepium* treatments and lower values recorded in early, normal and late planting under maize monoculture treatments (Fig. 7). In all farming practices, the leaf area index in the *G.sepium*-chololo pits combination increased by 40-42% compared to 32-35 % and 25-28% in maize-*G.sepium* and maize monoculture, respectively (Fig. 7). These results suggest that maize plants growth had significantly higher performance in *G.sepium*-chololo pits and maize- *G.sepium* than in maize monoculture.

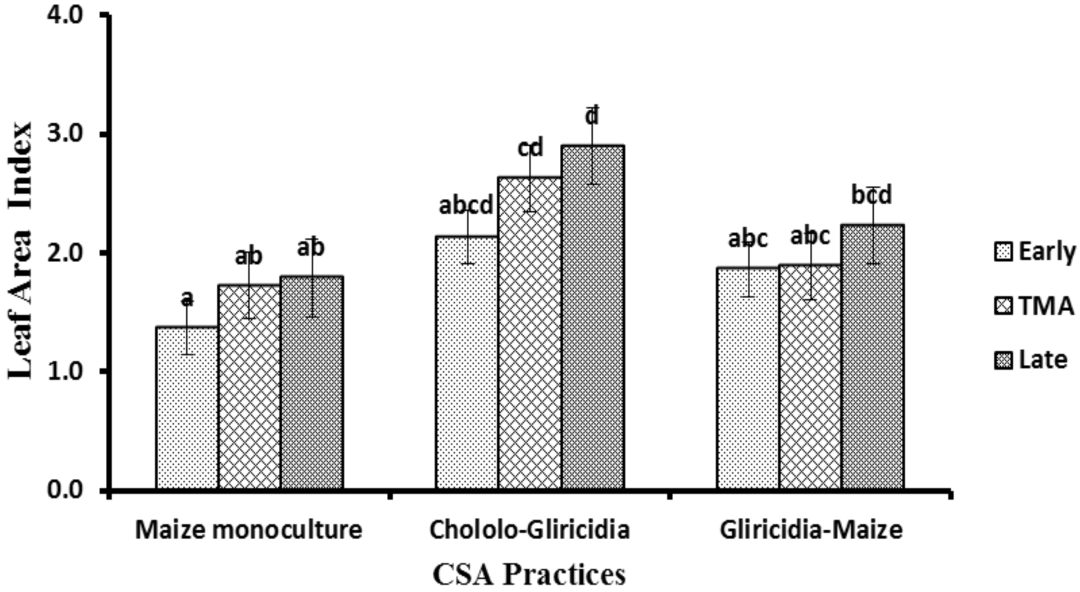

Figure 7: **Effect of planting windows and CSA practices on leaf index (LAI) at Laikala Village, Kongwa District, Dodoma. Means bearing same letter(s) do not differ significantly at P≤0.05 according to Tukey's test (n = 9).**

4.3 Maize biomass and grain yield

Overall maize dry biomass and grain yield varied significantly (p=0.001) between treatments **(**Appendix 3& 4)**.** In all farming practices tested, high maize yield was observed in the chololo pits-*Gliricidia*, followed by Maize- *G.sepium* intercropping and maize monoculture (Fig.8). Maize biomass yield ranged from 3.3 to 13.7 t/ha, and Maize grain yield ranged from 2.5 to 4.2 t/ha. The highest biomass yield was recorded in combination between late planting and *G.sepium*-chololo pits (13.7 t/ha), and the lower maize biomass had observed at early planting in maize alone (3.3 t/ha) **(**Fig. 8**).** However, grain yield was significantly (p>0.05) high (4.2 t/ha) for maize normal planted time in *G. sepium* treatment with rainwater harvesting using chololo pits. The intercropping between maize and *G. sepium* increased significantly maize grain yield by 23% compared to maize monoculture **(**Fig. 9**).** Early and late planting in maize alone treatment recorded the lowest maize grain yields (2.5- 2.6 t/ha).

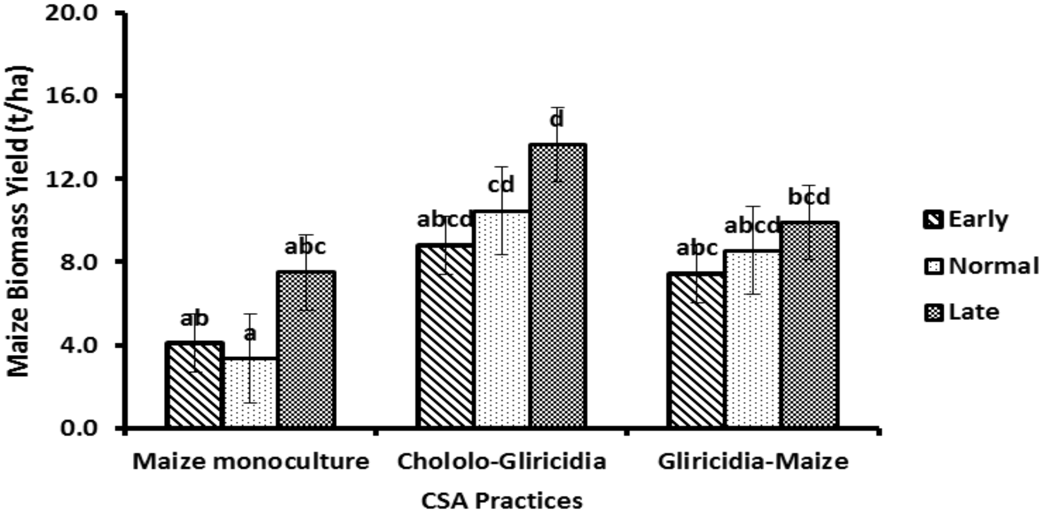

Figure 8: Effect of planting windows and CSA practices on maize biomass yield at Laikala Village, Kongwa District, Dodoma. Means bearing same letter(s) do not differ significantly at P≤0.05 according to Tukey's test (n = 9).

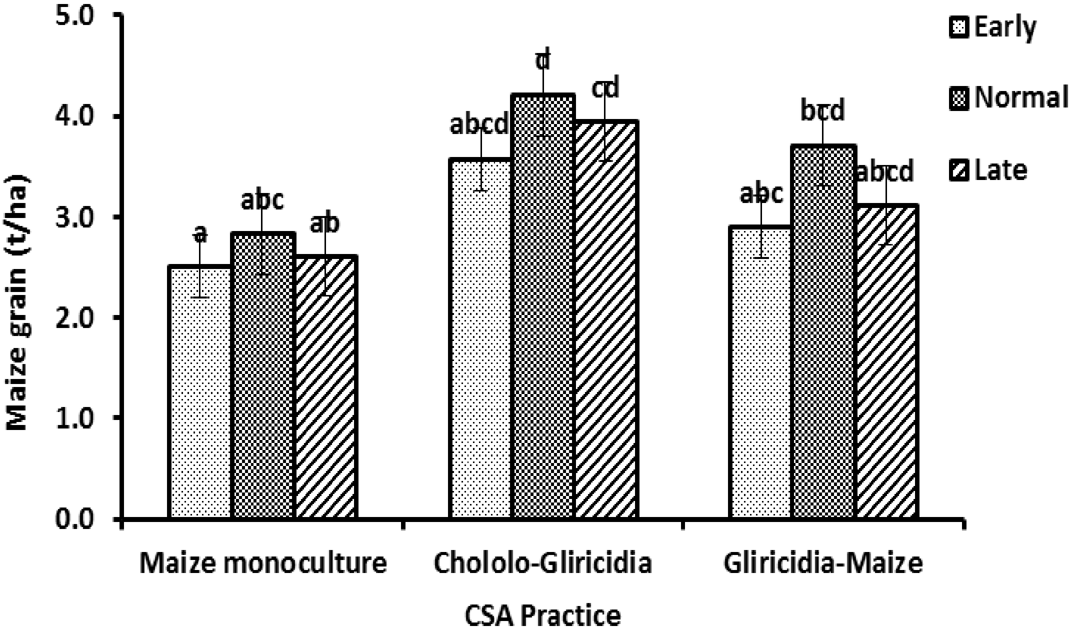

Figure 9: Effect of planting windows and CSA practices on maize grain yield at Laikala Village, Kongwa District, Dodoma. Means within a cropping

system bearing same letter(s) do not differ significantly at P≤0.05 according to Tukey's test (n = 9).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of *G. sepium* intercropping and chololo pits on soil moisture

G. sepium-chololo pits, maize-*G. sepium* intercropping treatments had higher significant soil moisture than maize monoculture plots due to the presence *G. sepium* and micro-basin which have advantage of harvesting rainwater and storage (Fig. 5). The combinations of chololo pits and *G.sepium* increased water harvesting and soil water storage than maize monoculture even during the dry spelt period (late January to late February). *G.sepium* intercropping increased soil moisture due to increased soil organic matter. Previous studies have revealed that mulching from *G.sepium* leaves and twigs improves soil organic matter, increase soil holding water capacity, infiltration rate and decreases evaporation from soils (Kimaro *et al*., 2016; Thierfelder *et al.,* 2017). Similarly, a study by Nyengerai (2010) reported that basin/pits planting practice in dryland areas had increased efficiency in water harvesting.

Micro-condition created by chololo pits normally favors good establishment of the main cereal crops, making it possible for farmers to plant crops after the first rains. As reported in others studies smallholder farmers in Zimbabwe under basin practice have been planting three weeks earlier compared to farmers under conventional practice (Mashingaidze *et al.*, 2012). This was due to improved soil moisture storage in the basins which support seed germination just after few mm of rains (Mazvimavi, 2009). Furthermore, in Zimbabwe, the tied-ridge trial as the in-situ rainwater harvest technology improved significantly soil water content compared to conventional farming (Motsi *et al*., 2004; Thierfelder *et al.,* 2017).

5.2 Maize growth

The difference in maize plants growth observed among the treatments reflects responses to differences in planting time and farming practice. The high maize growth in early, normal and late planted maize treatments under *G.sepium* and *G.sepium*-chololo pits than maize monoculture (Fig. 7) can be linked to the effect of high soil moisture retained by *G.sepium*-chololo pits and high soil fertility contributed from *G.sepium* (Kimaro *et al*., 2016; Thierfelder *et al.,* 2017). The high leaf size of maize plants reflects optimally solar radiation utilization for photosynthesis and vice versa (Anjum *et al.,* 2011; Blum, 2005; Tardieu, 2014). The canopy stature determines the rate of light interception received and photosynthetic efficiency. Because plant growth (Photosynthetic efficiency) is a function of foliage characteristics like leaf surface area using solar energy and ability to close or open stomata may result into building of large size of leaves finally to high rate of grain filling (Amanullah *et al.,* 2013; Almodares *et al.,* 2013).

The lower plant growth observed under maize monoculture at all planting times than maize-*G.sepium* and *G.sepium*-mhololo pits intercropping (Fig. 7) might have been due to limited water availability for plant use. Under extreme drought condition photosynthetic rate CO_2 assimilation and fixation maybe reduced (Adelabu *et al.,* 2017). The rainfall data showed unequal rainfall distribution within the growing seasonal. Low precipitation was received in February (25mm), which was followed by a prolonged dry spell of 3-4 weeks between late January and late February (Fig. 1). Low growth of early planted maize could be attributed to moisture stress during the dry spell period, which coincided with the vegetative stage (Parthasarathi *et al*., 2013). Likewise, Hatfield *et al.* (2015) found limited water availability to plant during flowering has an adverse effect on its physiological status causing decline in photosynthetic rates and plant growth. Normally under limited soil water availability and progressive drought stress in maize result in poor maize plant growth hence low yield (Parthasarathi *et al*., 2013).

5.3 Maize biomass and grain yield

The highest and significant maize grain yield was observed at the normal planting window (Mid Dec to Mid Jan.) in chololo pits-*Gliricidia* and maize-*Gliricidia* than maize monoculture (Fig. 9), was probably due to the combined effects of water availability and improved soil fertility (Kimaro *et al*., 2016; Thierfelder *et al.*, 2017).

Soil water availability and improved soil fertility have been reported to produce positive effects on maize plant growth (Adelabu *et al.,* 2017). Based on soil moisture data presented in figure 6, the combinations of *G. sepium* and chololo pits increased soil moisture retention for intercropped maize than maize planted alone for the entire growing season (Sommer *et al.* 2014; Kimaro *et al.*, 2016; Thierfelder *et al.,* 2017). *G. sepium* and chololo pits plays a special role on the farm by improving water storage, nutrient cycling and increase both soil organic carbon, abundance and soil organisms (Sileshi et *al.*,2012; Ngwira *et al*., 2013; Kimaro *et al*., 2016). Chololo pits (basin planting) practice had more effects in the initial phases of conservation agriculture (CA) implementation because it facilitates early-season water harvesting as well as soil fertility improvements (Mupangwa, 2009; Nyengerai, 2010). Normally, maize plants utilizes sufficient soil moisture during their early stages of growth and development, enhances high biomass and grain filling (Fig. 6; Adelabu *et al.*, 2017).

CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Generally, there was remarkable difference in soil moisture content, maize growth and yield across the farming practices tested and planting times. The greater response of soil moisture and maize grain yield was observed at normal planting in chololo pits practice with *G.sepium* and lower maize grain at early and late planting under maize monoculture. This suggests that there is high response of maize plants growth and yield in chololo pits, *G. sepium* than maize monoculture. Therefore, higher maize grain yields in normal planting time across to for all farming practices this affirms that is the appropriate planting time (Mid Dec to Mid Jan.) for Kongwa.

It can be concluded that combined use of weather information and CSA practice in farming operations helps to build resilience and sustain maize production.

Recommendations

1. The normal planting time (Mid Dec to Mid Jan.) is recommended for attaining high maize production in Kongwa district and other sites with similar site conditions.
2. The use of chololo pits and *G.sepium* maize-based farming systems in semiarid areas should be promoted for improving maize production and build resilience.
3. Further studies combining chololo pits and other multipurpose tree species are recommended.

REFERENCES

Adelabu, A. B., and Modi, A. T. (2017). Planting Dates and Harvesting Stages Influence on Maize Yield under Rain-Fed Conditions. Crop Science, School of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, Scottsville, Pietermaritzburg, South Afric. *Journal of Agricultural Science*; Vol. 9, No. 9; 2017.

Ahmed, S.A., Noah, S., Deffenbaugh, T. W., Hertel W., Martin, J. (2012). Agriculture and Trade Opportunities for Tanzania: Past Volatility and Future Climate Change. Policy Research Working Paper No. 6132, World Bank.Pp45.

Akinnifesi, F. K. Makumba, W. Kwesiga F, R. (2006). Sustainable maize production using gliricidia/maize intercropping in southern Malawi. *Expl. Agriculture* volume 42. pp. 1–17.

Amanullah, R., Khattak, A. and Khalil, S.K. (2010). Effects of plant density and N on phenology and yield of maize. *Journal of Plant Nutrition* 32: 246-260.

Almodares, A., R.H. Hotjatabady and Mirniam, E. (2013). Effects of drought stress on biomass and carbohydrate contents of two sweet sorghum cultivars. *J. Environ. Biol.*, 34, 585–589.

Anjum, S., Farooq, M., Wang, L., Xue, L., Wang, S., Wang, L., Zhang, S., & Chen, M. (2011). Gas exchange and chlorophyll synthesis of maize cultivars are enhanced by exogenously-applied glycinebetaine under drought conditions. *Plant Soil Environ.,*57: 326-331.

Blum, A. (2005). Drought resistance, water-use efficiency, and yield potential—Are they compatible, dissonant, or mutually exclusive? *Australian Journal of Agricultural Research,56*: 1159-1168.

Cairns, J. E., Sonder, K., Zaidi, P. H., Verhulst, N., Mahuku, G. and Babu, R. (2012). Maize production in a changing climate: impacts, adaptation,and mitigation strategies. Advances in agronomy, Burlington: Academic press.pp. 1–58.

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F. and Thierfelder, C. (2013). Adapting maize production to climate change in sub-Saharan Africa*.* *Journal of Food Security* 5(3), 345–360.

Conway, D. and Schipper, F. (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia'. *Journal of Global Environmental Change* 21: 227-237.

Coulibaly Y. J., G. Kundhlande, N. A., Tall A., Kaur, H. and Hansen, J. (2015). What climate services do farmers and pastoralists need in Tanzania?, Baseline study for the GFCS Adaptation Program in Africa. CCAFS Working Paper no. 110, CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark. 89Pp.

Decagon deveices. (2015). Operator's Manual-AccuPAR PAR/LAI Ceptometer, Model LP-80, Decagon Devices, Inc., Pullman, Washington, USA. 34Pp.

Demeke, A.B., Keil, A. and Zeller, M. (2011) 'Using panel data to estimate the effect of rainfall shocks on smallholders food security and vulnerability in rural Ethiopia',. *Journal of Climate Change* 108: 185–206.

FAO. (2000). Fertilizers and Their Use (4th Eds.) International Fertilizer Industry Association, FAO, Rome, Italy.56pp.

FAO. (2011). FAOSTAT online database, available at link [http://faostat.fao.org] site visited on 12/9/2017.

FAO. (2013) .Climate-smart agriculture sourcebook. FAO, Rome, Italy.109pp.

Ghosh, A.,P. Dass, A. Krishnan, P. Kaur, R. Rana, K.S. (2017). Assessment of photosynthetically active radiation, photosynthetic rate, biomass and yield of two maize varieties under varied planting dates and nitrogen application. Division of Agronomy, Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi-110 012, India. *Journal of Environmental Biology* : 2394-0379.

Hansen, J.W and Indeje, M. (2004).Linking dynamic seasonal climate forecasts with crop simulation for maize yield prediction in semi-arid Kenya, Agricultural and Forest Meteorology. 45Pp.

Harvey CA, Chaco´n M, Donatti, C. (2014). Climate-smart landscapes: opportunities and challenges for integrating adaptation and mitigation in tropical agriculture. Conservation Lett 7:77–90

Hatfield, J., Prueger, L., & John, H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes, 10*: 4-10.

EU. (2014). Project report on a model of good practice in climate change adaptation and mitigation, Chololo EcoVillage.37pp.

Kaliba, A.R.M., Verkuijl, W., Mwangi, A.J.T., Mwilawa, P. and Moshi, A.J. (1998). Adoption of Maize Production Technologies in Central Tanzania. International Maize and Wheat Improvement, the United Republic of Tanzania, and the Southern Africa Centre for Cooperation in Agricultural Research.12pp.

Karuma, A. N., Gachene C. K. K., Msanya B. M., Mtakwa P. W., Amuri , N., Gicheru, P. T. (2014). Soil morphology, physico-chemical properties and classification of typical soils of Mwala District, Kenya. *International journal of Plant Soil Science* 4:156 -170.

Kassam, A., Friedrich, T., Derpsch, R. and Kienzle, J. (2015). Overview of the worldwide spread of conservation agriculture. *Journal of Field Actions Science Reports* 8:1–10.

Kimaro, A.A., Timmer, V.R., Chamshama, S.O.A., Ngaga, Y.N. and Kimaro, A.A. (2009). Competition between maize and pigeonpea in semi-arid Tanzania: Effect on yields and nutrition of crops. *Journal of Agriculture, Ecosystems and Environmental* 134:115–125.

Kimaro,A.A ., Mpanda,M.M., Rioux, J., Aynekulu,E ., Shaba, S., Thiong'o, M ., Mutuo,P ., Abwanda,S., Shepherd, K., Neufeldt,H. and Rosenstock,T.S. (2016). Is conservation agriculture 'climate-smart' for maize farmers in the highlands of Tanzania?. *Springer Science+Business Media Dordrecht* 105:217–228.

Kirui, V., Oseni, S. and Bebe, O. (2010). Evaluating accessibility and usability of dissemination pathways for delivering climate information and services to vulnerable groups in semi-arid Kenya. Research Application Summary. Second RUFORUM Biennial Meeting 20 - 24 September 2010, Entebbe, Uganda.58pp.

La Rovere, R., Kostandini, G., Abdoulaye, T., Dixon, J., Mwangi, W., Guo, Z. and Bänziger, M. (2010). Potential impact of investments in drought tolerant maize in Africa. CIMMYT, Addis Ababa, Ethiopia.54Pp.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon,W.P. and Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Journal of Science* 319: 607–610.

MAFC. (2014). Tanzania Agriculture Climate resilience plan-2014-2019.Tanzania.

Manzoni, S., Vico, G., Katul, G., Fay, P. A., Polley, W., Palmroth, S., & Porporato, A. (2011). Optimizing stomatal conductance for maximum carbon gain under water stress: A meta-analysis across plant functional types and climates. *Functional Ecology, 25*: 456-467.

Mashingaidze, N., Madakadze, C. and Twomlow, S. (2012). Response of weed flora to conservation agriculture systems and weeding intensity in semi-arid Zimbabwe. *African Journal of Agricultural Research* 7 (36):5069–5082.

Massawe, B.H.J. and Amuri, N.A. (2012). Agronomic Practices Review and Soil Test for Improved Maize Production in Kiteto and Kongwa Districts Tanzania. BACAS, Sokoine University of Agriculture, Morogoro, Tanzania. 120pp.

Mazvimavi, K. and Twomlow, S. (2009). Socio-economic and institutional factors affecting adoption of conservation farming by vulnerable households in Zimbabwe. *Agricultural Systems* 101 (1–2):20–29.

Mekuria, M. (2009). Sustainable intensification of maize-legume cropping systems for food security in eastern and southern. CIMMYT program no CSE/2009/024.

Meliyo, J.L., Kimaro, A.A., Mkoma. A.A. and Jimmy, S. (2014). Characterization of experimental sites in Kongwa and Kiteto Districts; Tanzania. Mlingano Agricultural Research Institute. National Soil Service, Tanga, Tanzania.pp45.

Mkoma, A. (2015). Response of maize to phosphorus in sole maize and maize-pigeonpea cropping system in semi-arid areas of Tanzania; A dissertation submitted in partial fulfilment of the requirements for the degree of master of science in soil science and land management of Sokoine University of Agriculture, Morogoro, Tanzania.pp19.

Mongi, I, H., Majule, A. E. and Lyimo, J.G. (2010). Vulnerability and adaptation of rain fed agriculture to climate change and variability in semi-arid Tanzania. University of Dar es salaam, Tanzania. Institute of Resource Assessment.710pp.

Motsi, E. K., Chuma, E. and Mukamuri, B, B. (2004). Rainwater harvesting for sustainable agriculture in communal lands of Zimbabwe. *Physics and Chemistry of the Earth* 29 (15–18):1069–1073.

Mupangwa, W. (2009). Water and Nitrogen Management for Risk Mitigation in Smallholder Cropping Systems. PhD thesis, University of the Free State, South Africa.pp39.

Morris, M., Kelly, VA., Kopicki, R.J. and Byerlee, D. (2007). Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines. Washington DC: World Bank. 5pp.

Ncube, B., Twomlow, S. J, Dimes, J. P., van Wijk, M. T. and Giller, K. E. (2009). Resource flows, crops and soil fertility management in smallholder farming systems in semi-arid Zimbabwe. *Soil Use and Management* 25:78–90

Nellemann, C. MacDevette, M. Manders, T. Eickhout, B. Svihus, B. Kaltenborn, P. (2009). The environmental food crisis – The environment’s role in averting future food crises. A UNEP rapid response assessment. United Nations Environment Programme, GRID-Arendal.pp56.

Nelson, G.C., Valin, H., Sands, R.D., Havlík, P., Ahammad, H., Deryng, D., Elliott, J., Fujimori, S., Hasegawa, T., Heyhoe, E., Kyle, P., Lampe, M.V., Lotze-Campen, H., d'Croz, D.M., Meijl, Hvan, Mensbrugghe, Dvander, Müller, C., Popp, A., Robertson, R., Robinson, S., Schmid, E., Schmitz, C., Tabeau, A., Willenbockel, D. (2014). Climate change effects on agriculture: economic responses to biophysical shocks. *Proc. Natl. Acad. Sci.* 111:3274–3279.

Ngwira, A., Aune, J. B., Mkwinda, S. (2012). On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conversation agriculture in Malawi. *Field Crops Res* 132 :84–94.

Ngwira, A. R., Thierfelder, C. and Lambert, D. M. (2013). Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. *Journal of Renewable Agriculture and Food Systems* 28: 350–363.

Neufeldt, H., Jahn, M., Campbell, B, M. (2013). Beyond climate smart agriculture: toward safe operating spaces for global food systems. *Agric Food Security* 2:12

Nyamangara, J., Masvaya, E. N., Tirivavi, R. and Nyengerai, K. (2013). Effect of hand-hoe based conservation agriculture on soil fertility andmaize yield in selected smallholder areas in Zimbabwe. *Journal of Soil and Tillage Research* 126:19–25.

Nyengerai, K. A. (2010). Conservation Tillage under Small-Holder Farming Conditions of Semi-Arid Zimbabwe: An Assessment of Crop Establishment, Dry Spell Mitigation, Maize Yield and Crops Response to Nitrogen. MSc thesis, Faculty of Agriculture and Natural Resource, Africa University, Mutare. pp47.

Omondi, P.A. (2014). Change in temperature and precipitation extremes over the greater Horn of Africa region from 1961 to 2010 .*International Journal of Climatology* 34: 1262-1277.

Osbahr, H., Dorward, P., R. Stern and Cooper, S. (2011). Supporting agricultural innovation in Uganda to respond to climate risk: linking climate change and variability with farmer perceptions', Experimental Agriculture 47(Special Issue 02): 293-316.

Parthasarathi, T., Velu, G., & Jeyakumar, P. (2013). Impact of Crop Heat Units on Growth and Developmental Physiology of Future Crop Production: A Review. *Journal of Crop Science and Technology 2* :1-11.

Rusinamhodzi, L., Corbeels, M., van Wijk, M., Rufinio, M.C., Nyamangara, J., Giller, K,E. (2011).A meta-analysis of long-term effects of conservation agriculture practices on maize yields under rain-fed conditions. *Agron. Sustain. Development* 31: 657–673.

Sileshi, G.; Akinnifesi, F.K.; Ajayi, O.C.; Chakeredza, S.; Kaonga, M.; Matakala, P.W. (2007).Contributions of agroforestry to ecosystem services in the Miombo eco-region of eastern and southern Africa. *Africa journal of Environmental Science Technology* 1:68–80.

Sileshi G W, Debusho L K, Akinnifesi, F K. (2012). Can integration of legume trees increase yield stability in rainfed maize cropping systems in Southern Africa? *Agronomy Journal* 104:1392–1398.

Sommer, R., Thierfelder, C., Tittonell, P., Hove, L., Mureithi, J., Mkomwa, S. (2014). Fertilizer use should not be the fourth principle to define conservation agriculture. *Field Crops Res*169 :145–148.

Tanzania Meteological Agency. (2016). Seasonal weather forecast, Forecast issued on 5th September, 2016, No. 16 Special Issue: October to December (vuli), 2016 rain Season.pp25.

Tardieu, F. (2014). Plant response to environmental conditions: Assessing potential production, water demand, and negative effects of water deficit. Drought phenotyping in crops: From theory to practice.pp42.

Thierfelder, C. and Wall, P. C. (2012). Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. *Journal of Soil Use and Management* 28:209–220.

Thierfelder, C., Mutenje, M., Mujeyi, A. and Mupangwa, W. (2014).Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal Area, Zimbabwe. *Journal of Food Security* 7: 15–3.1

Thierfelder, C., Rusinamhodzi, L., Setimela, P.,Walker, F. and Eash, N. S. (2016). Conservation agriculture and drought-tolerant germplasm: reaping the benefits of climate-smart agriculture technologies in Central Mozambique. *Journal Renewable Agriculture and Food Systems* 156: 99–109.

Thierfelder,C., Chivenge ,P., Mupangwa,W., Rosenstock, T,S., Lamanna,C., Joseph X. And Eyre, J.X. (2017). How climate-smart is conservation agriculture (CA)?– its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Springer Science+Business Media Dordrecht and International Society for Plant Pathology* 17:19-34.

Thornton, P.K., Jones, P.G., Ericksen, P.J., Challinor, A.J. (2011). Agriculture and food systems in sub-Saharan Africa in a 4 degrees C+ world. Philosophical Transactions of the Royal Society. *Journal of Mathematical Physical and Engineering Sciences* 369:117–136.

UNFCC. (2003). Vice President´s office Initial National Communication Under the United Nations framework Convention on Climate Change (), United Republic of Tanzania.pp35.

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B., Nolte, C. (2014). A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. *Field Crops Res* 155 :10–13.

Vrieling,A., Leeuw, D.E.J., Said, M.Y. (2013). Length of growing period over Africa: variability and trends from 30 years of NDVI time series. *Journal of Remote Sensing* 5:982–1000.

Winterbottom, R., Reij, C., Garrity, D., Glover, J., Hellums, D., Mcgahuey, M., and Scherr, S . (2013). Improving Land and Water Management. Working Paper, Installment 4 of Creating a Sustainable Food Future. Washington, DC: World Resources Institute.Pp45.

Zingore, S., Murwira, H. K., Delve, R. J. and Giller, K. E. (2007). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture Ecosystems and Environment* 119:112–126.

APPENDICES

Appendix 1: ANOVA showing that there is a significant difference between soil moisture among the farming practices tested at P≤0.05 according to Tukey test

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Farming_prctice	2	22.2696	11.1348	12.02	<.001
Plating_time	2	0.7141	0.3570	0.39	0.686
Farming_prctice x plating_time	4	1.1615	0.2904	0.31	0.865
Residual	18	16.6733	0.9263		
Total	26	40.8185			

Appendix 2: **ANOVA showing that there is a significant difference between Leaf Area Indices (LAI) among the farming practices tested at P≤0.05 according to Tukey test**

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Farming_prctice	2	22.2696	11.1348	12.02	<.001
Plating_time	2	0.7141	0.3570	0.39	0.686
Farming_prctice x plating_time	4	1.1615	0.2904	0.31	0.865
Residual	18	16.6733	0.9263		
Total	26	40.8185			

Appendix 3: **ANOVA show that there is a significant difference between maize biomass among the farming practices tested at P≤0.05 according to Tukey test**

Source	Df	Sum of Squares	Mean Square	F	P-Value
Block	2	7.858	3.929	0.97	
Treatment	8	239.507	29.938	7.38	0.001
Residual	16	64.916	4.057		
Total	26	312.281			

Appendix 4: **ANOVA show that there is a significant difference of maize grain among the treatments tested at P≤0.05 according to Tukey test**

Source	Df	Sum of Squares	Mean Square	F	P-Value
block	2	0.2587	0.1294	0.83	
Treatment	8	9.1531	1.1441	7.38	0.001
Residual	16	2.4819	0.1551		
Total	26	11.8938			