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坦桑尼亚半干旱农业生态区土壤有机碳累积气候变化和作物产量：以 **Kongwa** 区域为案例

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Soil Organic Carbon Accumulation, Climate Variability and Crop Production in Tanzania's Semi-arid Agro-Ecological Zone: A Case Study of the Kongwa District

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A Dissertation Submitted to the College of Resources and Environment in Partial Fulfillment of the Requirements for the Award of the Degree of Doctor of Philosophy in Agricultural Resources and Environment of the Southwest University

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Southwest University

Certification

The undersigned certifies that he has read and hereby recommends for acceptance by the Southwest University a dissertation entitled ***"Soil Organic Carbon Accumulation, Climate Variability and Crop Production in Tanzania's Semi-arid Agro-Ecological Zone: A Case Study of the Kongwa District"***, in partial fulfillment of the requirements for the Award of the Degree of Doctor of Philosophy in Agricultural Resources and Environment of the Southwest University.

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Prof. Xinhua HE

(Supervisor)

Date………………………………..

Declaration

I, **Msafiri Yusuph Mkonda** declares that this dissertation entitled; ***Soil Organic Carbon Accumulation, Climate Variability and Crop Production in Tanzania's Semi-arid Agro-Ecological Zone: A Case Study of the Kongwa District***, is accomplished by me under the directions of my supervisor and that it has not been presented and will not be presented to any other University for a similar or any other degree award. This is an independent study, all the reviewed work from other researchers are cited. Hence, this Doctoral degree thesis is submitted with no violation of academic ethic and standard.

Signature……………………

Date: ……………………………

Dedication

This dissertation is dedicated to my beloved parents who passed away some years ago; Mr. Yusuph K. Mkonda (*Father*) and Ms. Maria G. Kisinda (*Mother*) for their inspiring legacy on my academic foundation. I sincerely salute and bestow them *The Highest Medal of My Academic Achievement!*

May God Rest Their Souls in Eternal Peace, Amen!

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List of Abbreviations and Symbols

asl	above sea level
BD	Bulk Density
C	Carbon
Ca	Calcium
CA	Conservation Agriculture
CDM	Clean Development Mechanism
CC	Climate Change
CC&V	Climate Change and Variability
C/N	Carbon to Nitrogen ratio
CEC	Cation Exchange Capacity
CF	Conceptual Framework
CH_4	Methane
CMIP	Coupled Model Intercomparison Project
CO_2	Carbon dioxide
CRiSTAL	Community-based Risk Screening Tool-Adaptation and Livelihoods
CSA	Climate Smart Agriculture
DALDO	District Agriculture and Livestock Development Officer
DAP	Diammonium Phosphate
ET	Emissions Trading
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
FFS	Field Farm School
GCMs	Global Climate Models
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
Ha	Hectare
IC	Inorganic Carbon
IPCC	Intergovernmental Panel on Climate Change
IRA	Institute of Resource Assessment

K	Potassium
KP	Kyoto Protocol
LUC	Land Use Change
M	Mean
MALF	Ministry of Agriculture, Livestock and Fisheries
Max	Maximum
Mg	Magnesium
Min	Minimum
Mn	Manganese
N	Nitrogen
Na	Sodium
NAPA	National Adaptation Program of Action
N_2O	Nitrous oxide
NEP	Net Ecosystem Productivity
NPK	Nitrogen Phosphorus Potassium
NPP	Net Primary Productivity
OC	Organic carbon
OM	Organic Matter
O	Oxygen
P	Phosphorus
Pg	Peta grammes= 10_{15}g
pH	Potential of Hydrogen
PRA	Participatory Rural Appraisal
R	Mann-Kendall and Sen's Slope Test
R_2	Coefficient of Determination
RWH	Rainwater Harvesting
SOC	Soil Organic Carbon
SPSS	Statistical Package for Social Sciences
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa
SSR	Self Sufficient Ratio

SUA	Sokoine University of Agriculture
SWU	Southwest University
TMA	Tanzania Meteorological Agency
TSP	Triple Super Phosphate
UDSM	University of' Dar-es-Salaam
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nation Framework Convention on Climate Change
UNDP	United Nation Development and Population
URT	United Republic of Tanzania
USDA	United States Department of Agriculture
WB	Walkley & Black
WHO	World Health Organization
WRB	World Reference Base for Soil Resources
Yr	Year

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Ph.D. in Agricultural Resources and Environment

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Abstract

Various ecological and environmental indicators including climate change, soil fertility, water availability and proper agronomic practices that form optimal agricultural systems are needed to be integrated for increasing agricultural productivity in the Tanzanian semi-arid agro-ecological zone. Among these indicators, climate change and soil fertility are the major limiting factors to affect crop yields in this semi-arid agro-ecological zone. To improve crop productivity, this study assessed the accumulation of soil organic carbon (SOC), the trends of climate variability and crop production, and the rate of adopting conservation agriculture (CA) in the Kongwa District, a semi-arid zone in central Tanzania.

In doing so, climate data and soil samples were collected from two representative villages of Mnyakongo and Ugogoni. These the villages are located at (6°12′8.47″S, 30°23′25.25″E and 6°15′6.59″S, 30°27′8.78″E), respectively, with 900–910 m above sea level and are located in one of the most sensitive zones to climate stress. The annual precipitation varies with elevation and ranges from 400 mm at 900 m a.s.l. to 800 mm at 1000 mm a.s.l., and the dominant soils are fluvisols and vertisols. Field experiment was conducted between June and September, 2016, whereas, soil samples were collected from pits in July, 2016.

Furthermore, household surveys, informative interviews, physical observations, and group discussions were employed during data collection. The Walkley-Black

Method was used for SOC analyses, while the SPSS (version 20) and Mann-Kendall Test were important software for analyzing climate, crop yields and CA practices. Qualitative data were analyzed using the theme content analysis and Community-based Risk Screening Tool-Adaptation and Livelihoods.

Statistically, the data were presented as the arithmetic means of two replicates plus standard deviations. The variables were tested for homogeneity of variance and normality, and where necessary, the data were transformed prior to analysis. A Pearson's correlation coefficient was used to test the significant differences in the accumulation of SOC under different soil treatment. This technique was also used in testing the correction between crop yields and soil treatments.

The results exhibited that the accumulation of SOC was significantly greater in soils under organic fertilization (1.15 and 0.80 MgC ha^{-1} at soil 0-20 cm and 20-30cm depth) than under no-fertilization (0.35 and 0.30 MgC ha^{-1} at 0-20 cm and 20-30 cm) and decreased with increasing soil depths. Under these two soil treatments, the average yields for maize, sorghum and millet were about 1.8 tn ha^{-1} under organic fertilization and 0.6 tn ha^{-1} under no-fertilization. Specifically, maize yields ranged from 1.5 to 2.2 tn ha^{-1} while both sorghum and millet had 1.1–1.7 tn ha^{-1}. Therefore, yields were significantly higher under organic fertilizations than under no-fertilizations.

Besides, the mean annual rainfall or temperature (1980–2015) fluctuated at a decreasing (R^2 = 0.21) or an increasing trend (R^2 = 0.30). Comparatively, the yields for maize, sorghum or millet fluctuated at a decreasing trend at R^2= 0.07, 0.05 or 0.85, respectively. Correspondingly, it was found that the temporal increase in rainfall and temperature had positive (R^2 ~ 0.5) and negative (R^2 ~ 0.3) correlations with crop yields, respectively. In contrast, the decline in rains intensity and frequency had negative impacts to crop yields. Eventually, the yields decline had negative impacts to food security in the study region.

Moreover, there was insignificant rate of adopting CA as adaptation and mitigation measures to climate impacts. In this aspect, it was found that only 10% of the total farmland was under CA practices i.e. agroforestry, crop rotation, minimum tillage and mulching. Essentially, crop yields were significantly greater (1.7 tn ha^{-1}) under CA than (0.7 to ha^{-1}) without CA. This indicates that CA had significant contribution to

crop yields in the study area and thus, it needs to be advocated as adaptation measure to climate impacts.

Generally, rainfall variability positively correlated with SOC or crop yields. Thus, to increase crop production, there is an immediate need to apply manure, irrigation and drought-tolerant crop seed. These results confirm that the studied semi-arid areas are among the most vulnerable regions to climate change impacts.

Given this vulnerability, this study proposes a district adaptation plan to increase the resilience of smallholder farmers. Similarly, it calls for more proactive practices to intervene the authentic and potential consequences in the country. A serious action to improve agronomic practices, mitigate and adapt to climate change impacts should concurrently be a priority in semi-arid areas to limit the level of vulnerability.

Key words: Agro-ecosystems, Climate, Fertilization, Semi-arid areas, Soil organic carbon, Tanzania

坦桑尼亚半干旱农业生态区土壤有机碳累积气候变化和作物产量：以 Kongwa 区域为案例

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摘　要

大量的生态和环境指标，包括气候变化、土壤肥力、水分利用率以及达到最优农业系统的适宜农业措施需要整合，以提高坦桑利亚半干旱农业生态圈的农业生产力。在这些指标中，气候变化和土壤肥力是影响这一半干旱农业生态圈作物产量的主要限制因子。为了提高作物生产力，这项研究评估了坦桑尼亚中部半干旱带 Kongwa 区中土壤有机碳（SOC）的富集、气候变化和作物产量的趋势和采用保护性农业的比率。

本项研究，气候数据和土壤样品收集来自两个代表性的村庄 Mnyakongo 和 Ugogoni。这两个村庄的地理位置分别为 6°12′8.47″S, 30°23′25.25″E 和 6°15′6.59″S, 30°27′8.78″E，地平线处于 900–910 米而且位于对气候压力最敏感的地带之一。年降水量随海拔高度的变化而变化，从 900 m 处的 400 mm 到 1000 米处的 800 mm，其优势土壤为潮土和变性土。本研究从 2016 年 6 月至 9 月进行田间试验，在 2016 年 7 月从试验坑内采集土壤样品。

而且，运用家庭调查、信息采访、自然观察和群组讨论的方式去收集数据和相互检验。采用 Walkley-Black 方法分析土壤有机碳，用 SPSS 20 中的 mann-

kendall
检验法分析气候、作物产量和保护性农业，运用主题内容分析、基于群落的分险筛选调控工具和 Livelihoods 去分析定性数据。

在统计上，数据被表示为两个重复的算术平均值加标准差。对变量进行了方差齐性和正态性检验，在必要的情况下，数据在分析之前进行了转换。利用皮尔森相关系数检验了不同土壤处理下土壤有机碳积累的显著差异。该技术也用于检验作物产量与土壤处理之间的关系。

结果表明土壤有机碳的积累量在有机肥料（土壤深度 0-20 cm 为 1.15 MgC 每公顷；土壤深度 20-30cm 为 0.80 MgC 每公顷）的土壤中远高于未施肥（土壤深度 0-20 cm 为 0.35 MgC 每公顷；土壤深度 20-30cm 为 0.30 MgC 每公顷）的土壤，并且其随着土壤深度增加而减少。在两种不同的土壤处理下，玉米、高粱和

谷子的平均作物产量也是如此（施有机肥情况下为 1.8 顿每公顷；不施肥情况下为 0.6 顿每公顷）。特别地是，在施有机肥的情况下，玉米产量在 1.5～2.2 吨每公顷，而高粱和谷子的总产量分别为 1.1～1.7 吨每公顷。因此，有机肥下的产量显著高于无施肥条件下的产量。

此外，年平均降雨量或温度（从 1980 至 2015 年）分别以下降(R^2 = 0.21)和增加(R^2 = 0.30)的趋势而波动。与此同时，玉米、高粱和小米的产量均已一个下降的趋势（分别为 R^2 = 0.07, 0.05, 0.85）而波动。相应地，发现雨量和温度的暂时性增加与作物产量分别呈现正（R^2 ~ 0.5）和负（R^2 ~ 0.3）相关。相反，雨量强度和频率的下降对作物产量有负面的影响。最后，产量下降对研究区域的粮食安全产生了负面影响。

而且，采用保护性农业去适应和减缓气候变化的比率并不显著。这一方面，仅有 10%的农田是采用采用保护性措施（如即农林、轮作、免耕和覆盖）。但实质上，作物在保护性农业下的产量（1.7 吨每公顷）要显著高于无保护性农业条件下的（0.7 吨每公顷）。这表明保护性农业条件在研究的土地上对作物产量有显著的贡献，需要去提倡采用保护性农业适应气候影响。

通常情况下，降水变化与土壤有机碳或作物产量呈正相关关系。因此，为了增加作物生产量，急需实施肥料、灌溉和耐干旱的作物种子。这些结果证实了本研究的半干旱区域是最容易遭受气候变化影响的区域之一。

考虑到这一脆弱性，本项研究提出了一个区域性的调整方案，以提高小户农民的适应力。同样，这呼吁更多有前瞻性的措施去介入这个国家真实的和潜在的结果。在半干旱区域，为限制脆弱程度应该同时优先考虑提高农业措施、减轻和适应气候变化的影响。

关键字：农业生态系统，气候，肥料，半干旱地区，土壤有机碳，坦桑尼亚

Chapter One: General Introduction

1.1 Definitions of Key Terms

1.1.1 Soil Organic Carbon

Soil Organic Carbon (SOC) is among the most important soil entities that are useful for crop production (Lal 2008). Other significant soil components can be nitrogen, phosphorus and Potassium fertilizers just to mention a few. Soil organic management is substantial to SOC accumulation in the soil (Batjes *et al*., 2007). The accumulated SOC is potential for soil fertility and carbon sequestration (Munishi & Shear 2004; Liaudanskiene *et al*., 2013). It significantly improves crop yields, food security and mitigation of greenhouse gases.

SOC stock varies from one agro-ecological zone to another depending on natural and human factors (Liaudanskiene *et al*., 2013). The amount of carbon stored in soil is determined by the balance of two biotic processes: production of organic matter (OM) by terrestrial vegetation and its decomposition by soil organisms (IPCC 2000). While decomposition of OM is controlled by temperature, water, soil chemical properties (i.e. mineral, pH, cation etc.) and soil physical properties (e.g. Structure, texture etc.), its production is controlled by physical, chemical and biological factors.

These factors range from climate, soil moisture, nutrient availability, plant growth and tissue allocation (Reeves 1997; Glaser *et al*., 2001; Bationo *et al*., 2006; Hartemink *et al*., 2008). In turn, management practices on the soil have significant influence on these factors. A number of research findings from different scholars (Lal 2004; 2008; Baldock 2007; Batjes *et al*. 2007; Batjes 2011; Kumar and Nair 2011; Jiang *et al*., 2014) just to mention a few, have assessed the quantity of carbon accumulation in various countries. Though, Tanzania has limited information on this.

Since 1990s, semi-arid areas of Tanzania have been facing frequent food shortages as a result of various environmental stresses (URT 2014). The main causes for this crisis are excessive droughts accompanied by poor agricultural systems. In explaining these causes, the former is a result of climate change impacts while the latter is a fault of farmers (Rowhani *et al*., 2011). Thus, if these two issues are not addressed; more occurrences of food shortages are expected to happen.

In Tanzania, there is a limited documentation of SOC on the basis of agricultural systems (Rossi 2009). A few studies have been conducted estimating SOC in some ecosystems, mainly forests (Elberling *et al*., 2007; Rossi 2009; Kaaya *et al*., 2013). Therefore, an estimation of SOC ought to be extended to different agricultural systems and farming practices (Mäkipää *et al*., 2012). This should be done to determine the amount of useful soil nutrients for plant uptake. In Tanzania's semi-arid zone, the situation is even worse, thus, it needs more assessment.

1.1.2 Climate Change

According to IPCC (2014), climate change refers to any change in climate over time due to natural variability or as a result of human activities. Further, the United Nation Framework Convention on Climate Change (UNFCCC) defined it as a change in climate that is attributable directly or indirectly to human activities that alter atmospheric composition. Olmos (2001) further defined it as the changes in the average climate in long-term trends such as changes in temperature and rainfall. Thus, climate change is a long-term change of elements of weather such as temperature, rainfall, humidity and sunshine just to mention a few. However, the local people mostly perceive it as change in terms of rainfall patterns (onset and cessation).

Different authors have investigated the existing reality about climate change based on scientific analysis and the community perceptions. Climate change is perceived by the majority of the rural people as a shortage of rainfall which leads to poor yields. The study by Mongi *et al*. (2010), showed that most people can detect climate change by using the decrease or increase, onset and cessation of rainfall.

On the other hand, Westengen and Brysting (2014), in their research, realized that the other indicator is the yields obtained. If all these aspects were less, they called that season a "bad year" (Mongi *et al*., 2010). Subsequently, the people or community became then vulnerable to that climatic stress (Agrawala *et al*., 2003; Adger 2006; URT 2007; Aldy *et al*., 2010; Ahmed *et al*., 2011).

1.1.3 Climate Variability

According to Orindi and Murray (2005) climate variability refers to the variation around the average climate including seasonal variation in atmospheric and ocean circulation such as the EI Nino and Southern Oscillations. Similarly, Mongi *et al.* (2010) further defined it as the shift from normal experienced rainfall pattern of seasons to abnormal rain pattern including temperature. The impacts of climate change and variability are some of the primary environmental concerns of the 21st century, and this has direct and indirect effects on people's lives. Therefore, one can say climate variability is a short term change of weather condition in specific areas with an earmark on the temperature and rainfall.

1.1.4 Vulnerability

Vulnerability is likelihood that an individual or a group of individuals will be exposed to and adversely affected by dreadful conditions (Aldy *et al*., 2010; Challinor *et al*., 2014). Similarly, Polskya, *et al*. (2007) and Olmos (2001) further defined vulnerability as characteristics of individual or groups in terms of their capacity to anticipate, cope with, resist and recover from the impacts of environmental change. Adger (2006), described it as a state and as a set of factors that constitute that state and dispose certain individuals and groups as "vulnerable". Other scholars, Turner *et al.*, (2003) added that it is a function of three overlapping characteristics: *exposure*, *sensitivity*, and *adaptive capacity.*

Table 1.1 below shows examples of factors that influence vulnerability in the aspects of institutions, economic and environment. Therefore, vulnerability may refer to the actual and potential risks that someone can be affected to as a result of poor adaptive capacity. For example, the people in semi-arid areas are vulnerable to food insecurity due to crop failure that is mainly caused by climate change impacts.

Table 1.1: Examples of factors that influence vulnerability

Institutional Factors	Economic Factors	Environmental Factors
i. Informal skills ii. Local knowledge iii. Formal education, skills and technology iv. Informal network v. Formal security network vi. Strength of local institutions	i. Labour ii. Health iii. Access to natural resources iv. Access to communal resources v. Access to alternative economic opportunities	i. Risk Environment ii. Degraded environment iii. High dependence of climate sensitive sectors and natural resources iv. Communal lands and resources

Source: Modified from Eriksen and Noes, 2003

Most rural areas of Sub- Saharan countries have poor institutions that could reduce the level of vulnerability in their region (Adger 2006). Economic factors are also limiting the capacity to adapt to dreadful conditions. Economic factors involve lack of asset and entitlement failure of natural resources (IPCC, 2014). Entitlement failure of natural resources leads to degradation of common resources with little economic return. Semi-arid areas of Tanzania are among the areas that experience frequent food shortages and thus, measures need to be taken to curb the situation.

1.1.5 Farmers Responses to the Impacts of Climate Change and Vulnerability

Farmers' response to the climate change impacts is determined by a number of factors. Adaptation capacity (resource endowments and assets), nature of agro-ecological zone and the magnitude of the impacts are among the factors. According to Paavola (2008), a wide range of small scale farmers in Tanzania have been responding by expanding the area under cultivation, shifting to drought resistant crops like sorghum, millet and cassava, while some adjusted to other economic activities such as charcoal burning. The adopted drought resistant crops are significant to the people in the sense that they provide food and income (see Table 1.2). Despite of these measures, the final destination to full resilience appears to be still far.

Table 1.2: Percentage of utility among the key crops in semi-arid areas of Tanzania

Crop	Food	Cash	Food &Cash	Total (%)
Millet	75	1.3	23.7	100
Maize	80	0	20	100
Sorghum	75	5	20	100
Average (n=80)	76.6	2.1	21.3	100

Source: Modified from Mkonda, 2011

Table 1.2 above shows the percentage of utility for each crop. Maize seems to have significant contribution to food (80%), while millet is for both food and cash (around 24%). Likewise, sorghum seem to contribute highly (5%) for cash compared to around 1% and 0% of millet and maize respectively. These utilities help to boost the socio-economic development of the people.

1.2 Statement of the Problem

Crop production in most semi-arid areas of Tanzania is significantly low (Mkonda 2011). As a way of limiting this deficit, some extension and agricultural officers have examined the better way of improving the existing farming systems i.e. cropping, livestock keeping and agro-pastoralism, however, this has not yet been fruitful. Under such a situation, most semi-arid zones experience frequent food insecurity and abject poverty. Small holder farmers are subjected into days, weeks, months, years and decades of unsustainable livelihoods. Some studies have been done relating to these aspects; however, they have not yet brought insights to planners and policy makers as they were less integrative. They either involved few stakeholders or focused on a single item. In this era of global climate change, there is a need to integrate numerous ecological aspects such as soil fertility, moisture conservation and proper agronomic practices to optimize nutrient cycling, adapt and mitigate climate change impacts (Solomon *et al*., 2000; Glaser *et al*., 2001; Rowhani *et al*., 2011; Challinor *et al*., 2014).

Although the science of detecting changes in crops yields, SOC and climate impacts is progressing rapidly, variety of knowledge gaps still exist. This research was geared towards filling this gap; the assessment of SOC under different soil managements and linking them with crops yield. This will happen, considering that this is an era of global climatic changes. Therefore, it will determine and explore the potentials of organic fertilizations to smallholder farming in the semi-arid zone of Tanzania which mostly receives rainfall of less than 600mm per annum. The knowledge about the impact of organic fertilizations on soil fertility is not only important for understanding the ecology of semi-arid, but also for evaluating the potentials and constraints for agricultural production.

This work assessed the accumulation of SOC under organic and no-fertilization scenarios, trend of climate variability and crops production in Kongwa District, a semi-arid area in central Tanzania. The amount of accumulated SOC and temporal climate variability were compared with the trends of maize, sorghum and millet production. In this aspect, SOC and climate variables were the determinant factors of crop production and thus, to increase crop yields; the adjustment should mainly be acquainted on these major variables. In this era of changing climate, there is a need to establish SOC database of high quality in the area for mapping and up scaling (Liebens and VanMolle 2003). In using the above mentioned entities, the issue of soil variations was controlled through classification to avoid misinterpretation.

1.3 Rationale of the Study

The study has multiple benefits to both farmers and the environment (IPCC 2014). Organic fertilizations increase important soil nutrients such as SOC, nitrogen, phosphorus, potassium and calcium just to mention a few, that have significant contribution to optimal soil fertility and environmental services. The increased adoption of organic fertilizations will raise nutrient cycling and uptake by the plants.

Under such a situation, farmers will get expected yields from maize, sorghum and millet to curb food insecurity and abject poverty (Giller *et al*., 2006). In addition, IPCC (2014), realized that accumulated SOC in agricultural field regulates climate through seizing the greatest greenhouse gases (GHG's) i.e. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Thus, apart from elevating crop yields, SOC serves as adaptation and mitigation measure to the impacts of climate change.

In addition, the study enables policy makers and planners to have a wide choice of options when establishing any agricultural plan in different agro-ecological zones of the country. Hence, this can bring some good outcome to farmers in the country.

The study can also be potential to other socio-economic projects, be it climate, agriculture or environmental projects that ought to explore climate and soil information aiming at bringing insights to the widest possible audience. This study is a stepping stone for further research and a good repository for academic purposes i.e. reference for scientific citation at national, sub-Saharan African and beyond (Mkonda *et al.,* 2018).

Overall, the study anticipates at improving the livelihoods of millions of Tanzanians living in semi-arid areas who strive to lessen hunger and abject poverty. Further studies can be conducted basing on agro ecological zone, or/and soil types (soil orders) of the country.

1.4 Materials and Methods

1.4.1 The Study Site

This study was carried out in the Kongwa District, the semiarid zone of Central Tanzania between June and September, 2016. The elevation of the District ranges 900-1000m a.s.l. and located on the leeward side of Ukaguru Mountains. It is located between latitude 5˚30' to 6˚0'S and longitude 36^{o} 15' to 36^{o}E, with an area of about $4041km^2$. The vegetation type of the Central Tanzania is of bush or thicket. Total annual precipitation in the area is 400–600 mm with a maximum of rain between December and April and a mean annual temperature is 26°C. According to World Reference Base for Soil Resources (WRB), the soils are classified as Chromic Luvisols (FAO 1988), with a sandy loam texture. The silt contents of the soils at the different farms were not significantly different (P >0.05) and ranged between 170 and 255 g kg^{-1} soil with a bulk density between 1.25 and 1.65 Mg m^{-3}. The soils are neutral to alkaline pH values, medium levels of organic C, N, P, K and trace soil elements. It has moderately high cation exchange capacity and high base saturation

The current population of Kongwa District is estimated to be 318,995. Out of these, 156,982 are males and 162,013 are females. This population grows at a growth rate of 2.4% per annum. There is moderate population growth due to sustained rural –

urban migration, which is prompted by a search for better employment prospects. The number of households is 60,301 with an average size of 4.9 people. The number of farming households is 45,271 which are almost equal to 90% of the total households. Labor force engaged in agricultural farming is 90 percent (of which farmers are 85 percent and livestock keepers are 5 percent).

The dominant farming systems are cropping, livestock keeping and agro-pastoralism. The area has 117,598 cattle, 73,196 goats, 33,896 sheep, 32,592 pigs and 2,656 donkeys (District Agricultural and Livestock Development Officer, 2016).These animals are potential as they can provide manure to farmers. Chemical fertilization is insignificantly applied in the area because it only focuses in irrigation schemes especially along Ikoka, Mzeru, Chelwe and Mlanga rivers.

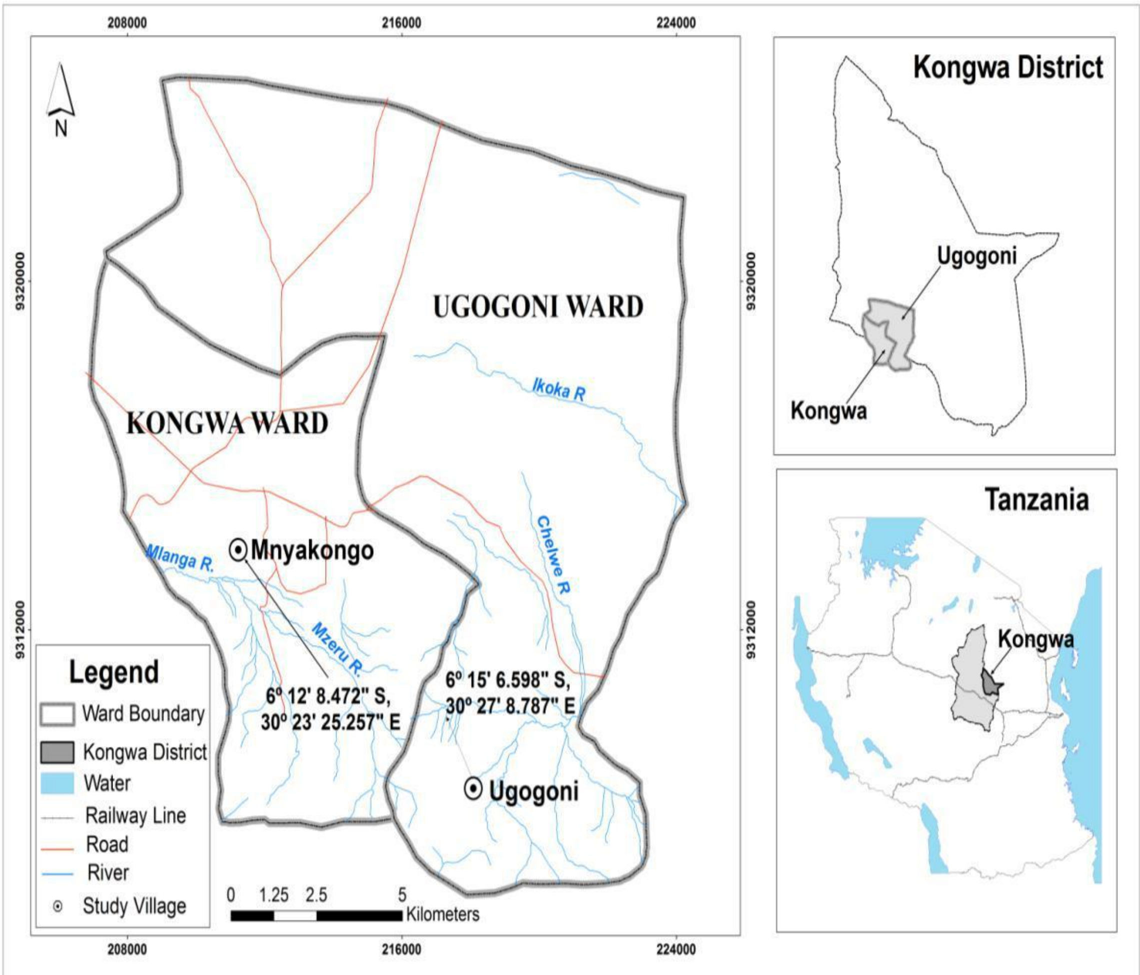

Figure 1.1: A study Area

Source: IRA GIS Lab, UDSM: 2016

1.4.2 Methodological Approach

1.4.2.1 Research design, sampling procedures

In this study different research methods were employed to collect both quantitative and qualitative data from primary and secondary sources. Both purposive and random sampling techniques were employed to select samples and locations. The research employed numerous approaches to collect the required data. It involved field soil sampling, household surveys, interviews, discussion, physical observations, solicitation of secondary data from the Ministry of Agriculture, Livestock and Fisheries, and Tanzania Meteorological Agency. Reconnaissance survey was done in order to explore the general ground knowledge and applicability of the research tools and techniques.

To have justifiable results on the farmers' perception, it was worthwhile to know their demographic characteristics especially age and academic levels. Since the study was conducted in rural areas, it was not expected to have more respondents with secondary education or above as most learned people migrate to urban areas for better jobs. That is why; about 70% of the respondent had primary education and were between 25 and 85 years as shown in Table 1.3.

Table 1.3: Summary of demographic and farming characteristics of respondents in the study sites

Variables	Percentage
Age	
i. 18-33	7.2
ii. 34-53	25.5
iii. 54-73	60.5
iv. > 73	6.8
Sex of the Household Head	
i. Male	62.8
ii. Female	37.2
Marital Status	
i. Married	90.3
ii. Single	7.7
iii. Divorced/Separated	2.0
Level of Education	
i. Primary	72.3
ii. Secondary	20.2
iii. Post-secondary certificates	4.1
iv. University	3.4
Experience in farming	
i. 10–19	40.2
ii. 20–39	55.3
iii. ≥ 40	4.5
Agricultural practices	
i. Crop production	60.5
ii. Livestock keeping	10.2
iii. Mixed farming (i.e. crop and livestock)	29.3
N	400

Source: Field Data Survey, 2016

1.4.2.2 Data collection

This study was carried out between June and November 2016. Soil samples were collected at the depth of between 0-30cm (<30cm) from July-September, 2016 in the two representative villages of Mnyakongo and Ugogoni (Figure 1.2).

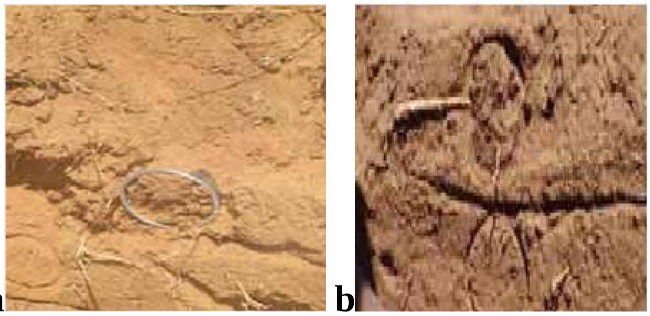

Figure 1.2: Soil sampling in Mnyakongo (a) and Ugogoni Villages (b) in the study area. This type of soil profile sampling in Tanzania was also done by Mäkipää*et al*. (2012).

The samples involved two depths (0-20cm and 20-30cm) which were taken from two situations (farm under organic and no-fertilizations). Finally, samples were ready for laboratory analyses. Other respective data for this study were collected based on various approaches (Table 1.4).

Table 1.4: Summary of questionnaires administration and PRAs tools in the selected villages

	Mnyakongo	Ugogoni
Questionnaires (n=400)	Total HH (2050)	Total HH (2080)
Number of households interviewed	200	200
Crop farmers (%)	70	80
Livestock farmers (%)	10	10
Both crop and livestock farmers (%)	20	10
Focus group discussion (n=30)		
Number of people participating in group discussion	15	15
Crop farmers	12	10
Livestock farmers	0	2
Both crop and livestock farmers	3	3
Interview (n=20)		
Number of people participating in Informative interviews	10	10
Crop farmers	8	9
Livestock farmers	0	0
Both crop and livestock farmers	2	1

Abbreviations: PRA, Participatory Rural Appraisal; HH, Household heads; n, sample

Source: Field Data Survey, 2016

Temporal rainfall and temperature data (1980-2015) were collected from the Tanzania Meteorological Agency (TMA) and the meteorological stations in the study area (e.g. Kinyasungwe). Yields data for maize, sorghum, and millet (1980-2015) were collected from Kongwa District Agricultural and Livestock Development Officer and the Ministry of Agriculture, Livestock and Fishery. Besides, ecological issues (i.e. degradation, droughts etc.) were solicited and determined at field level and from secondary data.

Essentially, a total of 400 questionnaires were collected from household heads of smallholders (farmer/livestock households) as seen in *Appendixes*. The questionnaires involved both closed and open questions. The selection of households was done by dividing the total number of the households in each village by the required sample size (about 10%) as seen in Table 1.4. The household lists were obtained from village government leaders in the study area whereas; a systematic sampling method was used by applying the following equation:

K=N/n (1) Saunders (2011) pointed that, for systematic sampling,

K (household*)* should be

selected in every studied population. *N* is the total number of the households in the community and *n* is the chosen sample size.

Participatory Rural Appraisal method (PRA) was also used to collect socio-economic data in the area. PRAs include informative interviews, group discussion and physical observation. The application of the PRA method has been used in various studies to explore perceptions of rural communities on environmental issues that affect their lives (Cramb *et al*., 2004; Brown 2006; Humphrey and Kimberly 2007).

In the present study, the PRA was used to acquire data on climate, yields and environmental changes.

Figure 1.3: Interviews with elders in Ugogoni Village (a) and Mnyakongo Village (b) respectively, and with a farmer in Mnyakongo Village (c), and a discussion with farmers in Ugogoni Village.

Source: Field Survey Data, 2016

One discussion group comprising 15 people was organized in each village. The discussants were mainly farmers and livestock keepers. A total of 20 interviews were conducted with extension officers, agricultural officers, seed breeders, irrigation engineers, meteorologists and land management experts, village farmers, livestock keepers and village government leaders. In this category, a checklist of questions encompassing a wide range of questions regarding the main theme of the study was used (*See Appendix A*). Lastly, scientific works such as books, journal papers, government reports and academic dissertations just to mention a few, were sources of secondary data especially during the establishment and development of the study.

1.4.2.3 Data analyses

Soil analyses were done at the Department of Soil Sciences and Geological Studies at Sokoine University of Agriculture. The Walkley-Black Method was used for SOC analyses. Yields data from the Ministry of Agriculture and those collected in the study area (i.e. from respondents) were parameterized, compared and averaged to acquire a reliable and representative data package.

Quantitative data for rainfall, temperature and crops yields were analyzed using Mann-Kendall Test (at 95% level of confidence), Ms-Excel and SPSS (version 20) software while Pearson's Moment correlation coefficient two-tailed test, and regression analyses were used to compare the trends of rainfall and temperature variability versus crop yields, and extrapolation of the future correlations (McCullagh 1974). P-values less than 0.05 were supposed to be statistically significant ($P < 0.05$). Qualitative data were analyzed through theme content analysis and Community-based Risk Screening Tool-Adaptation and Livelihoods (CRiSTAL) method.

1.4.2.4 Conceptual framework

A conceptual framework (CF) is a sketch descriptive presentation of variables to be studied and their theoretical relationships between them. Kajembe (1994), warned that any research performed without the guidance of the conceptual framework, is usually sterile for the reason that the researcher does not know quite well what data to collect, when to have them and how to put them into use. Therefore, hereunder is a conceptual framework designed to fit this study (Figure 1.4) and has clearly given a summary of the salient features of this study.

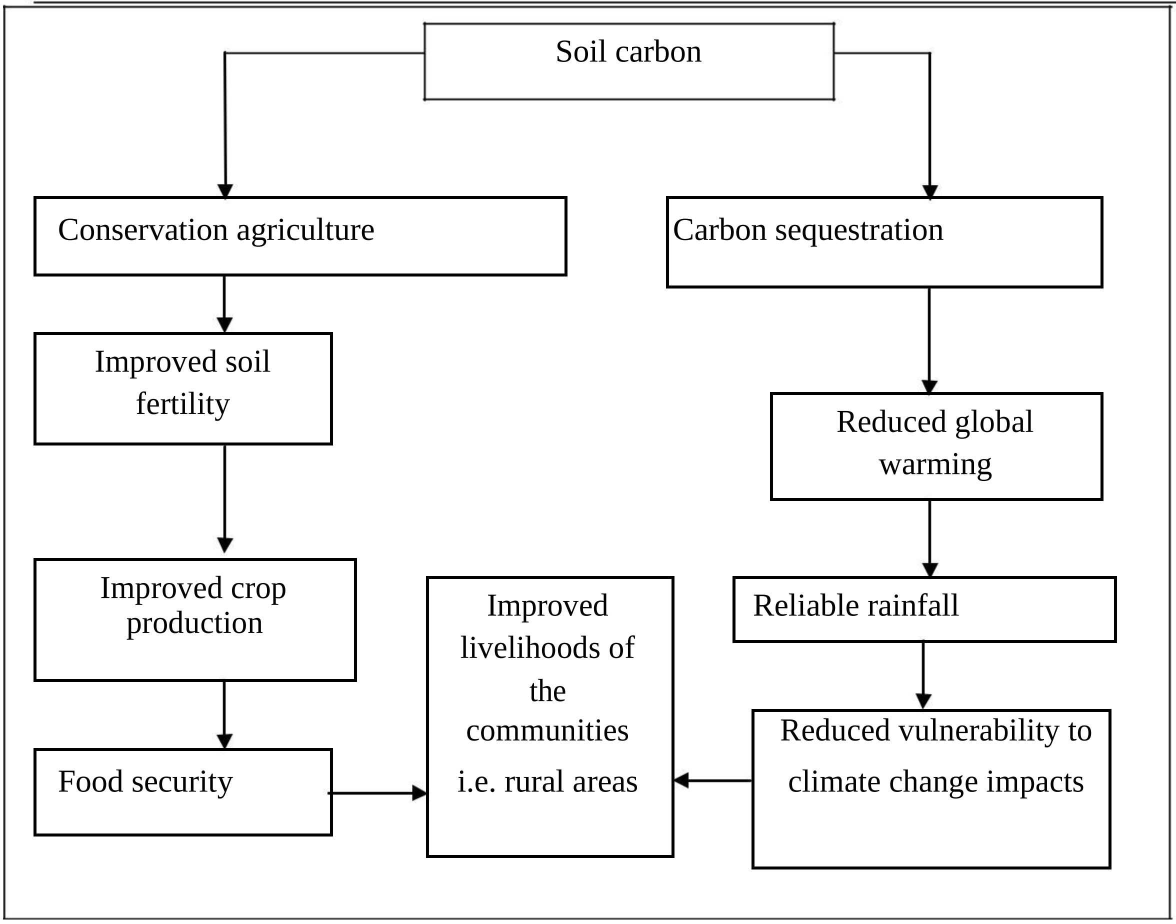

Figure 1.4: The Conceptual framework of the study
Source: Created by the Authors, 2016

Figure 1.4 above describes the graphical flow and inter-relationships among the significant components forming the study. In this concept; soil organic carbon plays a significant role of improving soil fertility, carbon sequestration, and increasing crop yields. Biological fertilizers and other soil amendments can work better than chemical fertilizers in improving crop production and reducing the emission of greenhouse gases.

1.5 Objectives of the Study

1.5.1 General Objective

The aim of this study was to assess the accumulation of soil carbon under organic fertilizations and no-fertilizations to optimize crop yields under climate change scenario in Kongwa District.

1.5.2 Specific Objectives

i. To carry out laboratory chemical analyses of SOC and other related parameters and assess their potentials to crop yields.
ii. To analyze the temporal production trends of major food crops (i.e. maize, sorghum and millet) for the past 35 years and show their implications to food security.
iii. To establish the correlation between the trends of climate variability and that of maize, sorghum and millet production for the past 35 years.
iv. To assess the adoption level of conservation agriculture in the area.

1.5.3 Research Questions

i. What are the laboratory chemical analyses of SOC and other related parameters in the soils, and their potentials to crop yields?
ii. What are the temporal production trends of the major food crops (i.e. maize, sorghum and millet) for the past 35 years and their implications to food security?
iii. What is the correlation between the trends of climate variability and that of maize, sorghum and millet production for the past 35 years?
iv. What is the adoption level of conservation agriculture in the area?

1.6 Format of the Dissertation

I structured my study in a series of six chapters to form this doctoral dissertation. There is an abstract which summarizes the main findings of all objectives that form this study. Out of six, four chapters are about the designated specific objectives of the study. The dissertation begins with the general introduction in Chapter 1 that describes about the study content, statement of the problem, rationale, and profile of the study site with map illustrations, methodology, conceptual framework and objectives. Chapters 2 to 5 analyze the SOC, present issues around the concept of climate by farmers and other stakeholders, trend of climate change and crop production based on statistical analyses, correlation between climate changes, SOC and crop production, and adoption level of conservation agriculture. These aspects form the major themes of this study.

Therefore, each chapter has its own introduction, methodology, results, discussion and conclusion. Specifically, Chapter 2 presents the accumulation of SOC in the study area. Chapter 3 accounts for the production trends of maize, sorghum and millet. Chapter 4 establishes the correlation between the trend of climate change and that of crops production. Chapter 5 assesses the adoption level of conservation agriculture in the study area. Finally, chapter 6 syntheses the main findings and implications of the whole study (all chapters).

Chapter Two: Accumulation of SOC and the Related Variables under Organic and No-fertilizations, and its Influence to Crop Yields in Tanzania's Semi-arid Agro-ecological Zone

2.1 Background Information

The present study focuses on the accumulation of soil organic carbon (SOC) and its influence to crop yields in semi-arid agro-ecosystem (Rossi 2009; Usuga *et al*., 2010; Batjes 2011; Araujo *et al*., 2017). Carbon (C) exists in the soil in the form of organic and inorganic. Organic carbon (OC), a main component of soil organic matter is formed by elemental carbon such as coal, charcoal, and graphite while inorganic carbon (IC) is composed of carbonate minerals, such as calcite and dolomite (Rossi 2009, Nelson & Sommers, 1982). Its deposit exists in thousand 1000s Pg around the world. The accumulation understudy is mainly attributed by soil organic management i.e. organic fertilization (Batjes 1992; Sombroek *et al*., 1993). Lal (2008) clarified that despite climates and vegetation having significant contribution to SOC accumulation at global level, soil organic management is prominent in doing so at farm level. Besides, soil depth has significant influence on SOC accumulation in various agro-ecology (Wang *et al*. 2010). However, the results from quantum calculation of SOC may have spatial and temporal variation (Nelson and Sommers 1982; Johannes *et al*. 2017; Sollinsa and Gregg 2017). Among other things, this variation is caused by land use change (LUC) and other natural factors.

The amount of carbon stored in soil is determined by the balance of two biotic processes namely; production of organic matter (OM) by terrestrial vegetation and its decomposition by soil organisms (IPCC 2000; Roose and Barthes 2001; Lal 2004; Vanlauwe *et al*. 2014). Soil organic matter (SOM) mainly comes from the remains of plants and animals, and is constituted by many organic chemical components (carbohydrates, lipids, proteins) which are carbon sources for the microbial activity of the soil. Thus, it is certain that SOC increases through the decomposition of SOM. Significantly, Batjes (1996) realized that accumulation SOC is a key component of any terrestrial ecosystem, and any variation in its abundance and composition has important effects on many of the processes (i.e. agriculture) that occur within the system.

Tanzania has limited studies that explore the accumulation of SOC under different soil managements (Kaaya *et al*., 2013; Shelukindo *et al*., 2014; Vanlauwe *et al*., 2014). Some of these studies have examined fertility and organic matter stability of savanna soils, permanent acacia cropping, accumulation of SOC under permanent sisal cropping and the effects of manure in homestead fields on organic C and N mineralization (Hartemink 1997; Glaser *et al*. 2001; Hartemink *et al*., 2008). Other studies have estimated SOC under natural ecosystems such as forestry and pasture but with very limited information on cropland (Munishi and Shear 2004; Elberling *et al*. 2007; Rossi *et al*. 2009; Mäkipää*et al*., 2012; Kaaya *et al*., 2013). Thus, very little has been done in explaining the same on semi-arid agro-ecosystem i.e. among the most vulnerable ecosystems in Tanzania.

Many semi-arid soils of Tanzania have poor nutrients especially when the farming systems are not well conducted (Palm *et al*., 2001; Roose and Barthes 2001; Vanlauwe 2004; Wang *et al*., 2010). Thus, to optimize soil nutrients in these areas, there is a need to adopt good agriculture practice (Kimaro *et al*., 2015). Among others, soil organic management can have a good attribute on this aspect (UNFCCC 2007; Baddeley *et al*. 2017). Various scholars have established that the soils under organic management are rich in organic matter with moderate permeability (Glaser *et al*., 2001; Lal 2004; Solomon *et al*., 2000). Apart from animal dung, soil organic management comprises the decomposition of plant biomass and animal residuals (Christensen 1988; Duan *et al*., 2011).

In most cases, the existing complexity that happens during the interaction among chemical, biological and physical processes necessitates proper soil organic management to achieve optimal soil fertility (Glaser *et al*., 2001; Lal 2008; Araujo *et al.*, 2017). This is because a wide range of soil nutrients, i.e. carbon, nitrogen, phosphorus, and moderate pH are attainable under soil organic management (Kimaro *et al*., 2015; Baddeley *et al*., 2017). These nutrients increase yields of various crops such as maize, sorghum and millet after boosting the interaction between soil microbes and plant roots to facilitate nutrients uptake (Bationo *et al*., 2006). However, various studies recommend the carbon/nitrogen ratio in the soil to be 1:30 for best practices.

Specifically, SOC plays a significant role in supplying plant nutrients, enhancing cation exchange capacity, improving soil aggregation and water retention, and supporting soil biological activities more especially the soil microorganisms i.e. mycorrhizae fungi (arbuscular mycorrhizae) and plants roots (Rossi 2009; Usuga *et al*. 2010; Batjes 2011; Smith *et al*. 2011; Araujo *et al*. 2017; Bokhorst *et al*. 2017; Qin *et al*. 2017). For example, mycorrhizae absorbs nutrients and water from the soil and provide to plant roots (facilitates the nutrient uptake by plants) while the plants provide carbohydrates to mycorrhizae (Nelson and Sommers 1982; IPCC 2000; Lal 2004; Rossi 2009; Wang *et al*., 2010). Further, these mycorrhizae optimize the resistance of plants to pathogens (Deckers 2001; Roose and Barthes 2001; Lal 2008; Haoa *et al*., 2016).

Although the science of assessing the changes in the soils fertility in various agro-ecological zones is progressing rapidly (Mishra *et al*., 2017), a variety of knowledge gaps still exist. This is about the actual assessment of SOC accumulation under different soil treatment and its influence to crop yields in most semi-arid agro-ecological zones. The overall target of this study is to raise food security and socio-economic development in semi-arid areas of Tanzania (where most people are poor) by increasing crop yields. The yields optimization can be achieved by increasing soil fertility through organic fertilization. This approach is the most accurate and the simplest way of increasing soil fertility as per the life standards of the majority of people in the area. In doing so, we will have determined the exact potentials of organic fertilization in optimizing SOC concentration for soil fertility, increasing yields and providing energy for soil microbes.

Further, it will have significant contribution to farmers in the area and other marginalized rural communities in the mechanisms of coping, adaptation and mitigation to global climate change (Johannes *et al*., 2017). Consequently, despite the fact that the relation between an increase in organic matter input and its effects on the soil organic matter and yields has been established in most developed countries, it is quite understandable that the present study establishes this knowledge in a developing country where this knowledge is quite limited. Knowledge about the impact of organic fertilizations on soil fertility improvement is not only important for general understanding the ecology of semi-arid, but also for in-depth evaluation of the potentials and constraints of agricultural production in this vulnerable agro-ecosystem.

Therefore, the current study aimed at: (1) Quantifying SOC accumulation and other important soil nutrients under organic and no-fertilizations at different soil depths; (2) Evaluating the relationship between SOC under organic and no-fertilizations; (3) Establishing the correlations between SOC, crop yields and environmental services, and proposing its utility for agro-social issues. SOC was selected because it supplies adequately energy to mycorrhizae fungi that in turn help the process of nutrient uptake for crop growth and production (Smith *et al*., 2011). Thus far, to achieve these objectives, soil management was mainly hypothesized and tested against the SOC accumulation and yields.

2.2 Materials and Methods

2.2.1 Physiographic Description of the Study Site

Table 2.1: Main physiographic units and soils in Kongwa District

Physiographic units	km^2	Altitude	Lithology	Dominant Major Soils
Mountains	400	980-2000	mainly Precambrian gneiss	Luvisols, Phaeozems, Leptosols, Ferralsols
Uplands	641	920-980	Acid and intermediate Metamorphic rocks	Luvisols, Ferralsols, Cambisols, Arenosols
Lowlands	3000	900-920	Unconsolidated rock	Fluvisols, Vertisols, Gleysols, Solonchaks

Source: FAO-UNESCO (1988)

2.2.2 Farming Situation in the Area

In the study area the dominant agricultural farming systems are cropping, livestock and agro-pastoralism (Elberling *et al*., 2007). Monoculture has been a dominant system in the area and has resulted in the exhaustion of soil quality (Hartemink 1997; Glaser *et al*., 2001; Hartemink *et al*., 2008). Such situation has affected the production systems and thus, leading to poor yields and frequent food shortage (Christensen 1988; Duan *et al*., 2011).

To restore the situation, we need to assess the magnitude of soil fertility deficit under different soils management scenarios. This is because in areas under organic fertilizations, soil nutrients (carbon, nitrogen, phosphorus and potassium, just to mention a few) are abundant to provide favorable condition for crop production (Johannes *et al*., 2017). Application of animal dungs (manures) can be a reasonable solution as they increase the fore mentioned nutrients especially SOC to maintain soil productivity, however, the degree of magnitude depends on the amount applied (Christensen 1988; Duan et al., 2011). Literally, most farmers in the area have an average of 4-6 hectares per household that can easily be fertilized by animal dung collected from their (Palm *et al*., 2001; Vanlauwe 2004; Bationo *et al*., 2006). According to the District Agricultural and Livestock Development Officer of Kongwa, the District has 117,598 cattle, 73,196 goats, 33,896 sheep, 32,592 pigs and 2,656 donkeys, thus far, farmers can make use of dungs from these animals to fertilize the soil and optimize crop yields.

2.2.3 Soil Sampling

Soil samples were collected from pits in July 2016. Soil was sampled according to standard guidelines for soil description (Wilke 2005). Ugogoni and Mnyakongo villages which represent the highland and lowland zone were sampled for the study (Figure 1.1). Geographically, the sites were purposively sampled due to their easy accessibility and are reported frequent to experience food shortage. Despite the fact that the cropping systems may vary with topography; maize, sorghum and millet (crops under study) were the major food crops in the area and are mainly produced through monoculture and rotation. In terms of soil sampling requirements, the two villages were selected because both complied with the needs of the two treatments (i.e. farms with organic fertilization and no-fertilization) and had favorable soil types (Table 2.1). The village representatives were also consulted in the selection of the sampling sites.

In each village (site) we established two treatments (i.e. farm under organic fertilization, and with no-fertilization) each with two soil depths/profiles (0-20 and 20-40 cm), whereas, for each profile the field to establish four soil ditches was randomly selected (W x L x D = 40 x 50 x 40 cm). Then, using a 150 ml volumetric soil sampler

(6cm diameter & 5.3cm height) four soil cores in each established ditch as seen in Table 2.2 was sampled. In this respect, volume-specific samples at 5-cm-increments were collected in each soil profile without mixing horizons.

The two soil treatments were defined for more clarification. For the site to qualify as under organic fertilization or no-fertilization, it should have stayed in that status for at least five years. In this study, sites under organic fertilization are those farms where the application of animal dung (especially cow) has been enormous for a couple of years (over five years) while those under no-fertilization must have stayed for that couple of years without any fertilization and have pre-experienced soil exhaustion. It was quite simple to get the sites with no-fertilization as more than 70% of the farmers do not use any fertilization.

On the other hand, we had to make an in-depth follow up when determining and sampling the sites under organic fertilization. Fortunately, in both villages we afforded to get few farmers who have been using organic fertilization for a couple of years. Essentially, they had been doing so because of the availability of animal dungs from their homesteads. Climatically, the area receives a single rainfall regime and thus, there is a single growing season.

On that basis, even fertilization is done once a year at around October to December. With this respect, we sampled the farms that have been under organic fertilization for more than 5 years and have been receiving at least 28 tn/ha of animal dung per year. The said 28 tons were equivalent to about 8 trips of a lorry that carry 3.5 tons of dry animal dung (slightly mixed with soils) in each trip. This quantitative precedence was set by the experienced farmers. On that basis, the process of soil sampling was now concise, accurate and informative.

Table 2.2: Soil sampling per villages (sites)

Treatment	Depth (cm)	No. of samples (Ug)	No. of samples (Mn)
Organic fertilization	0-20	16	16
	20-40	16	16
No-fertilization	0-20	16	16
	20-40	16	16
Total	64	64	Grand total=128

Abbreviations: Ug, Ugogoni; Mn, Mnyakongo

Source: Field Soil Sampling

Overall, a total of 128 soil cores were sampled in all sites and treatments. Technically, the maximum depth of 40 cm was sampled because most agricultural tillage under small scale farming ends at that depth. This depth is a bit different from other countries like China where most soils are well developed with profiles far beyond 100 cm (Wang *et al*., 2010).

Later, the samples were air-dried, sieved and taken to the laboratory of Sokoine University of Agriculture (Department of Soil and Geological Sciences) for chemical analyses. Soil bulk density was also determined using a soil corer (stainless steel cylinder of 150 cm^3 in volume), since all soil particles <2mm were taken for analyses. Retrospectively, crop yields data were gathered in the study area i.e. from Kongwa District Council and from farmers. These data were cross checked where necessary for authenticity.

2.2.4 Laboratory Analyses of SOC and Related Variables

Soil samples from the field were air-dried, aggregated and sieved through a 2mm sieve to allow further chemical analysis. Thus, additional chemical soil analyses were made using only the soil fraction finer than 2 mm (Homann *et al.* 1995). The analyses of soils samples based on depths and treatments were done separately in order to make a relevant comparison among them. SOC was measured in the laboratory by the $K_2Cr_2O_7$–H_2SO_4 oxidation method of Walkey and Black (Walkley and Black 1934; Nelson and Sommers 1982; Mustafa and Roy 2008). The Walkley-Black method gives variable recovery of SOC. Nonetheless, standard conversion factors of 1.33 for incomplete oxidation and of 58% for 'the carbon: organic matter' ratio were commonly used to convert Walkley-Black carbon to the total organic-C concentration, even though the true factors vary greatly between and within soils because of differences in the nature of organic matter with soil depth and vegetation type (Grewal *et al*. 1991). On that basis, the mass of C per soil mass (%C), but for upscaling to land units, it was expressed as a C density (Mg C ha^{-1} to a 0-40cm deep).

For an individual profile with k layers, the equation of Batjes (1996) was used to calculate the amount of organic carbon in the whole soil profile:

$$SOC_d = \sum_{i=1}^{k} SOC_i = \sum_{i=1}^{k} \rho_i \times P_i \times D_i \times (1-S_i) \qquad (1)$$

$$SOC_i = \rho_i \times P_i \times D_i \times (1-S_i) \qquad (2)$$

Where k is the number of horizons, SOC_i is soil organic carbon concentration (Mg m^{-2}), ρ_i is the bulk density (Mg m^{-3}), P_i is the proportion of organic carbon (gC g^{-1}) in layer i, D_i is the thickness of this layer (m), and S_i is the volume fraction of fragments >2 mm.

However, global calculations of the pool of carbon in the soil are complicated by a number of factors. According to Batjes (1996) these factors include: (1) there is still limited knowledge of the extent of different kinds of soils; (b) there is limited availability of reliable, complete and uniform data for these soils; (c) the there is considerable spatial variation in carbon and nitrogen concentration, stoniness and bulk density of soils that have been classified similarly; (d) and also there is confounding effects of climate, relief, parent material, vegetation and land use.

Total soil nitrogen was analyzed using modified Kjeldahl procedure (Wilk 2005). Soil pH was measured by glass electrode using soil to water ratio of 1:2. Then, available phosphorus (P) was extracted using Bray 1 method and was determined by spectrophotometric procedure (Wilk, 2005). Exchangeable potassium was extracted using neutral 1.0 M ammonium acetate and estimated using flame photometer. Apart from (C %), total nitrogen (N %) and available phosphorus (P), other parameters were soil pH (H_2O and KCl), electrical conductivity (EC), the exchangeable magnesium (Mg), calcium (Ca), potassium (K) and sodium (Na), the cation exchange capacity (CEC), Zn, Mn, Cu and Fe. Bulk density from a sampler (for fine earth) was calculated based on different fertilizations in order to decide the cropping systems (Hunt and Gilkes 1992; Cresswell and Hamilton 2002). It was calculated basing on the formula; Bd=WFE/VolFE= (WTotal-WG) / (VolTotal-VolG) and where necessary that with gavels was done through; Cm = (%FE / BdFE) / ((%FE / BdFE) + (%G /BdG)). In other global studies a mean bulk density of 0.15 to 0.25 Mg m-3 has been used for organic soil, while that of around 2.65 Mg m-3 for gravels (Sombroek *et al.* 1993).

2.3 Results

2.3.1 Soil Carbon Accumulation

The results showed that SOC was significantly greater in soils under organic fertilization (1.15 and 0.80 $MgCha^{-1}$ at soil 0-20cm and 20-40cm depth) than under no-fertilization (0.35and 0.30 $MgCha^{-1}$ at 0-20cm and 20-40cm), and decreased with the increase in soil depth (P <0.05). Under both situations, SOC were the highest on the surface (0-20cm) and diminished with the increase soil depth (Figure 2.1 and Table 2.3). These results are in agreement with those by Liu *et al.* (2017), Haoa *et al*. (2016), Palm *et al*. (2014), Grand and Lavkulich (2011), Rossi (2009), Lal (2008), Elberling *et al*. (2007), Ellert *et al*. (2002) and Christensen (1988).

This happened because manure fertilization was mainly done on the top-soils, and thus, the concentrations of soil nutrients were found at that layer. In soils under no-fertilizations, there were non-significant differences (P >0.05) between the two horizons because most of the nutrients got lost through monoculture and leaching (Liaudanskiene *et al*., 2013). In addition, the moisture was higher in the soils with organic than no-fertilization as it was buffered by SOC from leaching (Wang *et al*. 2010).

Comparatively, SOC under organic fertilization had higher SOC than under no-fertilizations. Animal manure was the major factor for this difference. It was embraced with nutrients more especially carbon and added it in the soil. It was this difference which latter determined crop yields and environmental services.

Similarly, total nitrogen (TN) and phosphorus (TP) were significantly higher (P <0.05) under organic fertilization than in no-fertilizations and decreased from 0.40 and 2.40 Mg (0-20cm) to 0.16 and 2.10 Mg (20-40cm) respectively (Table 2.3). In addition, other important soil nutrients such as calcium (Ca^{2+}), potassium (K+), magnesium

(Mg^{2+}) and sodium (Na+) behaved in the same way (Table 2.4). The pH value of the soil increased significantly (*P* <0.05) where manure was applied, but remained constant under no-fertilizations (Table 2.4). The soil pH was neutral as it ranged from 6.5-7.5 under both situations (Mkonda and He 2018a).

The same trend was observed in Zn, Mn, Cu and Fe, whereby they decreased under no-fertilization. In addition, high concentrations of these elements were observed at 0-20 cm depth, and had significant ecological implications to crop yields and environmental services (Bokhorst *et al*., 2017; Liu *et al*., 2017, Qin *et al*., 2017). Nonetheless, attention was least given to these trace elements as the study intensely focused on SOC.

Table 2.3: Analyses result of soil samples from the study area

Field ref.	Depth (cm)	No. Samp*	TN-Kjeld	OC-BlkW	Ext.P (mg/kg)	CEC ($cmolKg^{-1}$)	Exch. Bases ($cmolKg^{-1}$)			
			(%)	(%)	PBry-1	CEC	Ca^{2+}	Mg^{2+}	K+	Na+
Org. Fertil.	0-20	32	0.40	1.15	2.40	36	14.4	5.53	3.23	5.15
Org. Fertil.	20-40	32	0.16	0.81	2.10	28	11.2	4.44	2.13	3.09
No. Fertil.	0-20	32	0.05	0.35	0.14	34	9.6	3.60	1.31	4.15
No. Fertil.	20-40	32	0.03	0.30	0.07	24	5.7	2.50	0.60	2.06

*****Samp. = Sampling; Org. Fertil. = *Organic Fertilization; *No. Fertil. =No-Fertilization

Source: Lab soil analyses at Sokoine University of Agriculture (SUA), 2016

Table 2.4: Analyses result of soil samples from the study area

Field reference	Depth (cm)	No. Samp*	Soil pH (1:2.5) (in H_2O)	$CaCl_2$	EC 200µS/cm	Zn mg/kg	Mn mg/kg	Cu mg/kg	Fe mg/kg
Org. Fertil.	0-20	32	5.48	6.11	39	0.89	6.97	0.40	17.98
Org. Fertil	20-40	32	6.18	6.21	36	0.83	4.13	0.25	15.98
No. Fertil.	0-20	32	6.80	5.25	32	0.34	2.81	0.04	13.46
No. Fertil.	20-40	32	6.58	4.57	30	0.32	2.20	0.04	10.47

*****Samp. = Sampling; Org. Fertil. = *Organic Fertilization; *No. Fertil. =No-Fertilization

Source: Lab soil analyses at Sokoine University of Agriculture (SUA), 2016

It was observed that, continuous cultivation of maize, sorghum and millet under no-fertilizations, decreased the SOC concentration by 50% within 5 years of comparison (Figure 2.1). Later, after 10 years of continuous cultivation, it caused a further loss by about 20% (Glaser *et al*., 2001; Bationo *et al*., 2006). Similarly, the lowest TN and TP concentration were found in long-term agricultural fields without manure fertilizations (P <0.05). Correspondingly, the highest cation exchange capacity (CEC), manganese (Mn) and iron (Fe) were significantly optimal under organic fertilizations but zinc (Zn) and copper (Cu) had no significant changes in both situations i.e. fertilizations (Table 2.4). They were not adversely affected by long-term cropping without fertilizations.

The cultivated land appeared to be transient of soil nutrients from the top soils to the bottom layers through leaching (Lal, 2008). However, it was difficult for uncultivated land which seemed to be compact, and thus, did not allow easy infiltration of soil nutrients. Therefore, organic fertilization seemed to have significant contribution to the accumulation of SOC and other elements in all labile as mentioned before. At farm level, it was evident that most farmers collected animal manure at the homestead before transporting them to the farm, where sometimes is a bit far.

This homestead collection happens for two major reasons: (i) most of the farmers keep few animals, i.e. less than ten by average, and thus, even the amount of produced manure is low; (ii) farmers aimed to reduce the transport cost whereby the most reliable means of transport seen in the study area is wheel trailer pulled by donkeys and cows. Eventually, the transported manure was deposited in the farms for use.

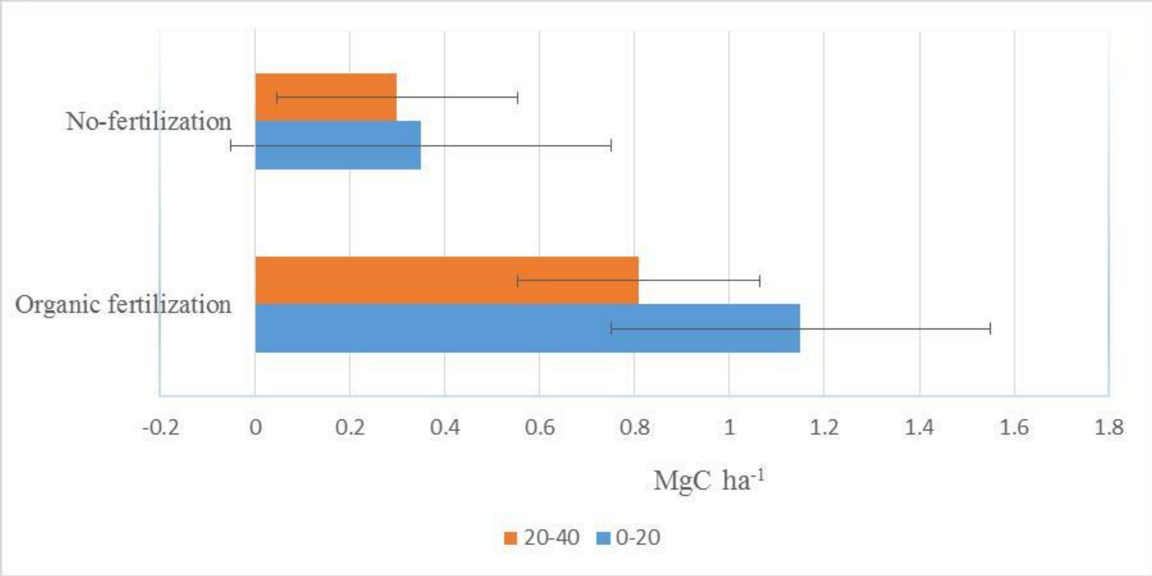

Figure 2.1: SOC accumulation under both organic and no-fertilizations in different soil depths

Source: Data analyses, 2016

In addition, soil bulk density (BD) was determined in this study. BD is expressed as the mass of an oven dry sample of intact soil per unit volume (Salifu *et al.*, 1999; Soil Survey Staff 2011). It is very important physical property which is needed for mass to volume or area conversions of soil properties. It is essential for the assessment of soil C stocks and nutrient pools (Lal, 2008) and in most cases, is the mandatory measuring unit for soil C assessment in CDM A/R (Clean Development Mechanism Afforestation/Reforestation) accounting (UNFCCC 2007).

Bulk density (BD) was calculated to determine the soil physical properties (Cresswell and Hamilton 2002). This was done to determine level of soil management in the area (Hunt and Gilkes 1992; Salifu *et al*. 1999).

$$\text{Thus, BD } [gcm^{-3}] = \frac{\text{Mass of dry soil sample [g]}}{\text{Sample volume [cm3]}}$$

Under such a situation, the volume was determined by coating a clod of known mass with a water-repellent substance and by weighing it first in air, then again while immersed in a liquid of known density, making use of Archimedes' principle (Vogel 1994).Thereby; mass of dry soil=173g (under organic fertilization) and 165g (under no-fertilization). Sample soils volume=149.77cm^3 (Calculated from the soil sampler with a diameter of 6 cm and height of 5.3 cm). Thus, πr^2 h: 3.14x3x3x5.3= 149.77cm^3. Then, BD= 173g/149.77=1.2g/cm^3 (under no-fertilizations) and 165g/149.77=1.1g/cm^3 (under organic fertilizations) and the value increased with depth.

Therefore, BD was less under organic fertilization than under no fertilization. This happened probably because there were more organic matter concentrations under organic fertilization than in the counterpart. In addition, the sub-surface layer in both conditions had higher BD than beneath. This happened because the bottom soil layers had reduced organic matter, aggregation, root penetration and compaction of soil from the above (Mishra *et al*., 2017; Cresswell and Hamilton 2002). In whole, both fertilizations had low BD because the samples were sieved in less than 2mm diameter and thus, they had fine texture. As a result, the soil had a recommendable BD for agriculture (Soil Survey Staff 2011; Hunt and Gilkes 1992). Then, SOC concentration was calculated by the following formula: SOC = Depth (cm) × Bulk density (gcm^{-3}) × Organic carbon (%)

Hence, SOC (0-20cm)

a. Under organic fertilization=20cm × 1.1 gcm^{-3} ×1.15 MgC ha^{-1} =25.3Mg ha^{-1} b. Under no-fertilization =20cm × 1.2 gcm^{-3} × 0.35 MgC ha^{-1} =8.5 Mg ha^{-1}

The concentration of SOC decreased basing on soil management and depths. These results of the present study provide an accurate assessment of SOC accumulation in semi-arid areas under the auspices of organic fertilizations and without it (IPCC 2003). The study highlights the potential activities that could significantly contribute to the accumulation of SOC and other related nutrients. It is this soil management that supports the level of soil C mineralization, and therefore, forming an important aspect for soil fertilization, carbon sequestration and adaptation to climate change impacts especially in the arid and semi-arid environments.

2.3.2 Crop Yields

The yields for seven years from either under organic or no-fertilizations were enough to determine the differences. The average crop yields (tn ha^{-1}) were correlated with soil treatments in the sampled villages. This correlation was done through Persons' correlation coefficient. There were significant difference in yields of maize, sorghum and millet under fertilization and no-fertilization (see Table 2.5). There were higher yields under organic fertilization than under no fertilization.

Table 2.5: Correlation (r) between average crop yields (tn ha^{-1}) and soil treatments in the sampled villages

Year	Organic fertilization				No-fertilization			
	Maize	Sorghum	Millet	*r**	Maize	Sorghum	Millet	*r**
2010	1.5	1.1	1.1	*0.35*	0.4	0.6	0.5	*0.27*
2011	1.6	1.2	1.1	*0.37*	0.4	0.6	0.5	*0.27*
2012	1.7	1.5	1.4	*0.42*	0.8	0.5	0.5	*0.29*
2013	1.6	1.4	1.6	*0.51*	0.5	0.5	0.5	*0.18*
2014	2.2	1.7	1.6	*0.56*	0.6	0.6	0.6	*0.23*
2015	2.1	1.6	1.6	*0.58*	0.6	0.5	0.5	*0.25*
2016	2.2	1.7	1.6	*0.63*	0.6	0.7	0.7	*0.27*

Source: Field Data Analysis, 2016

Abbreviation: *r** indicates Pearson correlation of the data (i.e. fertilizations and the overall crop yields) at 5% level of significance.

The average yields for all the crops were about 1.8 tn ha^{-1} under organic fertilization and 0.6 tn ha^{-1} under no-fertilization. Therefore, yields were significantly higher under organic fertilizations than no-fertilizations (Table 2.5). Maize yields ranged from 1.5-2.2 tn ha^{-1} while both sorghum and millet had 1.1-1.7 tn ha^{-1} (Table 2.5). Maize that appeared to be the most favorable and staple food (United Republic of Tanzania, 2014) responded well to organic fertilizations than sorghum and millet, but was adequately affected under no fertilizations (Table 2.5). Sorghum and millet appeared to be tolerant to nutrient-deficiency stress because they had almost a similar trend in all the five years (Table 2.5). However, this did not guarantee optimal yields as they had very low (0.5-0.7 tn ha^{-1}) yields at as seen in (Table 2.5).

2.4 Discussion

This study establishes a discussion on the quantitative assessment of SOC under different soils treatments. This is because in the study area there was no any study that has established the accumulation of SOC that would be a baseline study for the forthcoming studies. Thus, among other things, the present study serves as a baseline. It has revealed that there were significant correlations between the accumulation of SOC and soil managements ($P < 0.05$). Figure 2.1 indicates that there were more SOC in farms under organic fertilizations than under no-fertilization. This considerable increase in SOC was greatly attributed by the application of animal dung i.e. cow in the farms (organic fertilization). Again, the concentration of SOC was on the top soils (0-20 cm) than sub-soil (20-40 cm) because most of this soil organic managements are implemented in that top layer. This was even evident through the SOC calculation in Section 3.1 of this empirical paper. IPCC (2003) recommends the calculation of carbon densities for a given soil depth e.g. 0-30cm, 30-100cm more especially when most SOC is contained in the sampling depth. This is done because sampling may miscalculate the SOC in high bulk density (BD) as BD may be affected by tillage. As a solution, Ellert *et al.* (2002) recommended the expression of SOC amount on the equivalent mass basis.

Optionally, volumetric measurements can be corrected by adjusting the sampling depth. This involves the sampling of smaller depth in heavier soils or greater depth in light soils. In the present study, the BD and SOC stock were calculated to a fixed depth of 20cm for each horizon. A maximum soil depth of 40 cm was sampled because this is the considerable depth in which agricultural practices take place. This is good especially for the small scale farming which mostly uses hand hoe. Thus, this particular depth determined the influence of soil management to SOC accumulation (Baldock 2007).

This is fairly important because it increases the capacity of nutrients uptake by plants. To support this assertion, Kalhapure *et al*. (2013) and Nyadzi *et al*. (2006) confirmed that soil organic management increases the amount of soil mineralization more especially soil C, and therefore, increasing soil fertility and C sequestration. In the study site, the major source of organic fertilization was manure from sheep, goats and donkeys. Hence, the number of animal determined the magnitude of fertilization. In the area, the most herded households had an average of 30-50 cattle while the least herded were averages at <10 cattle. Therefore, there were major correlations between the number of herds and the acreage under organic fertilization.

On the other hand, there had been a serious decline of soil fertility under no-fertilizations (Figure 2.1). This study found the highest decline of crop yields was due to continuous cultivation without fertilizations, a situation that had exhausted high quantity of important soil nutrients (Figure 2.1). This confirms the findings from other studies which indicated high decline of soil fertility under a given soil management (Hartemink 1997; Glaser *et al*. 2001; Bationo et al. 2006; Haoa *et al*. 2006) just to mention a few. Under such a situation, important soil nutrients such as carbon, nitrogen, potassium, and phosphorus declined due to removal of cations. In these farms, plants had no sufficient nutrients for their growth, and thus, poor yields were obtained as seen in Table 2.5 above. Permanent cropping and continuous cultivation resulted into a negative balance of soil nutrients that need to be offset by soil nutrient pools (Hartemink 1997). Under such a situation, even the little elements which were difficult to be weathered were now depleted easily. This eventually affected crops yields and subsequently exacerbated abject poverty among the farmers.

On the other this study investigated the amount of organic manure or chemical fertilizers that have been applied by most farmers. It was confirmed that a sufficient amount of organic manure was applied by some households while chemical fertilizers was insignificantly applied (Table 2.6).

Table 2.6: Estimated use of OM and CF (i.e. per household) in the study area

Type of fertilizer	Mnyakongo	Ugogoni
Organic manure	15-30 tn/ha	15-25/ha
Chemical fertilizers	13 kg/ha	11kg/ha

Abbreviations: OM, Organic manure; CF, Chemical fertilization

Source: Field Survey Data, 2016

This was in agreement with the study objectives as it focused on organic manure than chemical fertilization as the later had less impact to crop yields. Meanwhile, under organic fertilization, the ability of organic matter (OM) to retain cations for plant utilization while buffering them from leaching was higher than in area without fertilizations (Yao *et al*., 2010). The cation exchange capacity (CEC) of OM is due to negative charges created as hydrogen (H) is removed from weak acids during neutralization (IPCC 2000). OM also reduces or buffers the change of pH in the soil when acids or bases are added in the soils (IPCC 2000). On that basis, crop yields would improve when other factors were constant (Henry *et al.* 2009).

The difference in water content of soil between the two sites (soils under organic and no-fertilizations) brought significant insights on the same. Fertile soils appeared to have high retaining water capacity than that under no-fertilizations because of high OM (under organic fertilization) buffers moisture that can get lost through leaching (Deckers 2001; Duan *et al*., 2011). Thus, when other factors were constant, agricultural fields with manure had high degree of moisture concentration than under no-fertilizations, thus optimizing crops yields on the former than the latter (Duan *et al*., 2011).

Results from informative interviews and household survey supported the results from analyses (Figure 2.1) as they informed that more maize, sorghum and millet yields were obtained under organic fertilization than under no-fertilization, albeit, all sites were hit by climate change impacts. They were assertive that, organic fertilizations were potential for crop yields.

By SOC being resilient from losing moisture and fertility, the agricultural fields under organic fertilizations acted as a sink of atmospheric carbon and thus mitigating climate change impacts by seizing carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) which are the first, second and third largest greenhouse gases respectively in contributing to global climate change (IPCC 2013; Kumar & Nair 2011). Mitigation of these gases can further increase resilience of the farmers in this era of global climate change.

The studies by Reeves (1997) and Rossi (2009) have similar observation on the same. However, Munishi and Shear (2004) specified that the amount of sequestered C is equivalent to that found in biomass (P <0.05). Thus, soil degradation leads to C exit to the atmosphere and for it to be seized back, we need to have sinks (plants).

To restore such a situation, organic fertilization has shown to be a good option (Kalhapure *et al*., 2013). It increases soil fertility and resumes the biological functioning of important soil microorganisms such as mycorrhizae fungi, optimizes photosynthesis, nutrients uptake, shoots and roots growth (Kimaro *et al*., 2015; Smith *et al*., 2011; Wang *et al*., 2010). Similarly, these fertilizations facilitate plant growth and resistance to pathogens which increases crop yields (He *et al*., 2010). At ground level, this was supported over 70% of the farmers who applied manure and got adequate yields.

In addition, an interview with District Agricultural and Livestock Officer (DALDO) confirmed that in areas where animal manure, straws or a combined animal + straws are applied, the yields of maize, sorghum and millet (food crops) have been optimal. Therefore, the adoption of organic fertilization is quite important because it leads to optimal crop yields which are a major source of livelihood among the farmers in the study area.

The findings of this study have similar observations with some authors, but slight differences with some others. The main reason for this difference is due to different soil types, climate, intensity of agro ecosystems, depth for soil analyses and parent materials just to mention a few (Christensen 1988; Davidson 1994; Batjes 1996; Bationo *et al*., 2006) who generally obtained SOC between 1.5-3.4 MgC in 0-30 depth. They mostly obtained it under tropical climates while the present study did so in the semi-arid climate.

Under natural condition, rainfall plays a significant role in the process of accumulating carbon in the soil. The change in moisture regime affects the decomposition of biomass (IPCC, 2000). Rainfall amount determines the amount of SOC that accumulates or exits (Elberling *et al*., 2007). Extreme low rainfall leads to excessive drought that limits the production of plant biomass and formation of OM in the soil, while high rainfall leads to high water content of the soil and eventually the decrease in decomposition rate of OM, and thus, further increasing SOC (Glaser *et al*., 2001; Baldock 2007).

In whole, Wang *et al*. (2010) realized that there is an exponential correlation between SOC accumulation and precipitation. In addition, the increase in temperature and decrease in rainfall are likely to reduce the Net Primary Productivity (NPP) and Net Ecosystem Productivity (NEP) albeit its magnitude may not be easily quantified. The areas experiencing drought due to dry spells and increased evaporation, have a lesser possibility to accumulate SOC (Hartemink *et al*., 2008). Usually, SOC accumulation increases from warm to cold and from dry to wet locations (Roose and Barthes 2001;

Usuga *et al*., 2010; Yao *et al*., 2010). Therefore, there is a significant correlation between climate and SOC accumulation (UNFCCC, 2007).

Potentially, the present study found that agricultural fields under organic fertilization had notably higher yields at 1.8 tn ha^{-1} than 0.6 tn ha^{-1} under no-fertilization (Table 5). This was because of the soil nutrients availability in the former than the latter. Similarly, organic fertilizations conserved the functioning of biological condition of the soil more, especially the mycorrhizae fungus and plant root synergies (Smith *et al*., 2011). The study by Wang *et al*. (2010) also found that there is exponentially positive correlation between SOC accumulation and biological functions. Thereby, an increased concentration of C in the soil will accelerate microbial processes, also will warm and moist the soil (Davidson, 1994).

For the assessment of the production potential of each crop, maize, sorghum and millet were compared. They responded differently under different fertilizations, cropping systems and economic potentials. All crops were optimal under organic fertilizations as they gave maximum yields at 2.2, 1.7 and 1.6 tn ha^{-1} for maize, sorghum and millet respectively. However, correspondingly they gave fewer yields under no-fertilization at 0.4, 0.5 and 0.5 tn ha^{-1} (as minimum yields) for maize, sorghum and millet respective.

Subsequently, there were significant differences ($P < 0.05$) in crops yields under different cropping systems. Maize had outstanding yields when intercropped with leguminous crops i.e. lablab compared with sorghum and millet. In addition, sorghum did well under long-term monoculture without fertilization than other crops. Under favorable weather, in the mixed cropping of the three crops; maize did better than others while sorghum was the best under stressed environment i.e. drought.

Thus, under poor soil, sorghum needs to be adopted as it gives optimal yields despite such unfavorable condition. Economically, there were no significant differences in the production process of the three crops. This is because all the crops used about the same cropping systems and preparation costs. On the other hand, the yield demands of the three crops appeared to have no significant differences ($P > 0.05$), however, during food shortage maize appeared to have high demand pressurized by the demands at national level. Under high yields, maize was sold at $0.5 per kg while sorghum and millet were sold at around $0.3 per kg. However, during food shortage this price doubled or trebled especially for maize.

Visits were done in some maize stores where maize is sold and realized that, there were significant different (P <0.05) in the price during harvest and at least six months after harvest. The price of maize during harvest was a bit affordable (around $0.3-0.4 per kg) than during scarcity when sometimes reaches to about $ 1 per kg. This price was extraordinary high to most food destitute. Therefore, economically, maize had high demand compared with sorghum and millet.

Here it can be summarized by confirming the hypothesis (H_I) that the accumulation of carbon and other important soil elements depended on depth, types of agronomy and the level of organic fertilization (soil organic managements). It is apparently definite that in areas with organic fertilization, the level of soil C is high and therefore, increases soil fertility for crop production. It is also seen that there are significant differences in crop yields between the two soil managements.

Basing on that, it is worthwhile to advise farmers to adopt organic fertilization in their farming because of the fore- mentioned potentials especially curbing frequent food shortages in most semi-arid of sub-Sahara Africa. This only happens when the said advantages (i.e. SOC) are quantified and established to the extent that a certain amount of SOC can suffice the required crop production.

2.5 Conclusion

The direct comparison of soil C storage between soil under organic and no-fertilizations showed that organic fertilization had higher SOC than the counterpart (no-fertilization). Again, the study revealed that the top 0–20 cm had more SOC than the 20-40 cm under both states. Similar trend was observed to other important soil nutrients/elements. Retrospectively, the farm with high SOC recorded higher crop yields than those without fertilization.

Among other things, SOC is useful in optimizing strategies of mitigating the accumulation of CO_2 in the atmosphere. This kind of information is crucial when effort is made to assess the soil C storage across various agro-ecological zones. Therefore, the present study has confirmed the hypothesis (H_1) as all hypothesized aspects have been confirmed.

On that basis, it has met its objectives as it has revealed the differential accumulation of SOC and its related aspects under organic and no-fertilization, different crop yields and provision of environmental services under the two soil management practices.

The results from the data analyses have supported the achievement the study objectives and the tested hypotheses. Therefore, intensive organic fertilizations seem to be a sustainable solution to the poor yields in this semi-arid environment, where there is increasing variability of rainfall amount and pattern.

Chapter Three: Yields of the Major Food Crops; Implications to Food Security and Policy in Tanzania's Semi-Arid Agro-Ecological Zone

3.1 Background Information

Insufficient food production has become the major problem in most developing countries. This is the central reason for food shortage in Sub-Sahara region (FAO 2003). According to UNDP (2012) the region has nearly 218 million people who are food insecure and undernourished. The report further clarifies that food security is a core component of the human development and capability paradigm. Thus, enhancing food availability and entitlements is a robust way to sustainable human development (Sen 1993; Conceição *et al*., 2016).

Countries like Burkina Faso, Mali, Niger, Malawi, Kenya and Tanzania have already been adversely affected by climate change (IPCC 2014; Mmbando *et al*., 2015). While climate is increasingly impacting the production, population growth has been increasing rapidly, and thus, food production has not been kept up with population growth (UNDP 2012). Since 2000s population projection shows that about 70% of African rural population who depend on locally produced food will be significantly affected by environmental stress (DESA 2001; ECA 2002).

It was further indicated that the growth rate of cereal grains (food crops) was 1% while that of population was 3%. Correspondingly, as from 1980s to 2010s, the per capita cereals production has decreased for about 15% (150–130) kg/person compared to Asia and South America whose figures progressed from 200 to 250 kg/person (FAO 2001; 2003). To raise the per capita cereal production, we need a sound agricultural/food policy that would be a central focus in relieving food shortage (Higgins, *et al*., 2015; Cornia *et al*., 2016). It is evident that most agricultural policies in the region are obscured by other sectoral policies such as environment, tourism, water and population which sometimes have contrasting procedures and regulations.

Thus, a robust food policy that harmonizes other allied policies is very important in closing the yield gap (See Figure 3.1). Further, advanced technology should be well explicated in this policy to allow rational implementations of various agricultural plans and programs (Ricker-Gilbert and Jones, 2015). The robust implementation of a well-articulated food policy can address the key issues that have been causing poor yields in the region (Seufert *et al*., 2017). The impacts of climate change, weak labor, weak technology and inadequate agricultural systems are among the key challenges that should be well addressed in the policy.

Despite of having low agricultural productivity, the Sub-Sahara Africa has not taken satisfactory efforts to elevate food security (FAO 2001). Instead, food requirement has increased for about 100 million tons of cereal food crops (maize, millet, sorghum etc.). For the past two decades, the food requirement gap has widened in the region despite the increase in food imports and aids to 180% and 290% respectively (from 16 to about 36 million tons) (Wart *et al*., 2012). Theoretically, low production has been happening because of ineffective utilization of the endowed environmental resources i.e. especially land (Lobell *et al*., 2009).

For instance, there has been increased soil degradation and deforestation by 16% and 70% respectively despite of being prohibited in most policies (FAO 2001; ECA 2002). Therefore, there should be mechanisms to synthesize the policy formulation and implementations. The present study locates in Tanzania where agriculture industry is a main source of food, energy, fiber, feed and other industrial raw materials (FAO 2001). It accounts for over 70% of the total economic activities and employs about 90% of the Tanzanians especially those in rural areas (URT 2014; 2009).

In addition, it provides up to 50% of the Gross National Product and 80% of the exports (Bagachwa 1994; URT 2013). Maize accounts for over 70% of the national starch requirements and is a staple food for over 80% of the people in the country (URT 2013). However, the country experiences frequent food shortage which is more pronounced in semi-arid agro-ecological zones. In due fact, the National Environmental Policy (URT 1997), National Water Policy (URT 2002), National Population Policy (URT 2006) and National Agriculture Policy (URT 2013) are alleged for not addressing this situation adequately.

It is widely understandable that there is a need to ensure effective utilization of the available resources to raise food security and socio-economic welfares. However, the two targets have been out of reach. For example, in 2013/2014 the food requirement was 7,656,673 tons, but only 5,613,221 tons were produced and thus, making a food deficit of 2,043,452 tons (27%), leading to serious implications to food security and poverty (URT 2014). This shortage was more pronounced in semi-arid zones. Furthermore, the food survey report of 2014 showed that semi-arid regions had more than 50% food deficit. In the midst of this vain, Paavola (2008), Mongi *et al*. (2010), Yanda *et al*. (2010), Kimaro *et al*. (2015) and Mtengeti *et al*. (2015) reported that climate change impacts and poor management of environmental resources were the major cause of food shortage and therefore, all the necessary and sustainable measures should be taken into serious consideration to curb them.

During food shortage, there has been a tendency of the farmers blaming the government for not giving them subsides and aids while the government reverse the blames to them for not copping with the drought. In the midst of this, policy issues need to be carefully looked at. Besides, the socio-economic role of NGOs or/and international development banks is not much reflected at local level as they are mainly operating at ministerial level.

Although the science of assessing the changes in the crop yields in various agro-ecological zones is progressing rapidly, variety of knowledge gaps still exist. This research was geared towards filling this gap of investigating the seasonal variability of food crop yields in semi-arid agro-ecological and their implications to food security and policy. This will enable policy makers to pay special attention to the most vulnerable and already affected areas when planning to optimize food security. Moreover, a robust food policy that explicitly touches the interest of the farmers can enable them to significantly cope with environmental stresses despite the limited resources.

Therefore, this study assessed the temporal production trends of maize, sorghum and millet (major food crops) in Kongwa District, the semi-arid area of central Tanzania to determine their contributions to food security and how food policy addresses this issue to make the country more food secure. Maize, sorghum and millet were selected because they are staple food crops and they determine food security for more than 90% in the country (URT 2007; Paavola 2008; Yanda *et al*., 2010 and Rowhani *et al*., 2011).

The findings of this study are expected to be useful to policy makers and implementers in agricultural sector at different level.

3.2 Materials and Methods

3.2.1 Conceptual Framework

This study uses a conceptual framework to capture important aspects of the study (Figure 3.1). This was purposively adopted to elicit the general and specific thoughts adopted in the study.

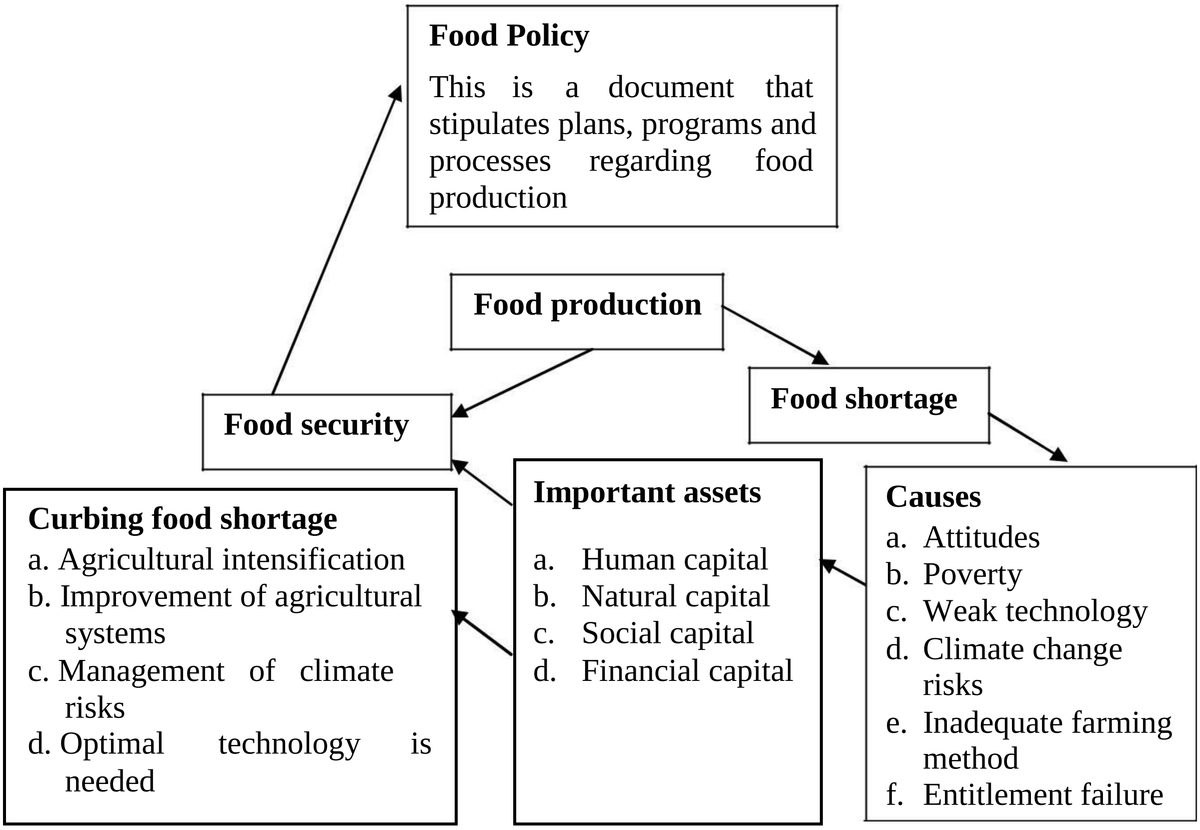

Figure 3.1: The Conceptual Framework of Food Policy

The above conceptual framework (CF) in Figure 3.1 indicates how a robust food policy can contribute significantly to yields optimization. The CF further clarifies that the major causes of poor yields can be poverty, weak technology, climate change risk and entitlement failure just to mention a few. These challenges need to be well addressed into the relevant policy to elicit the production. Best use of available assets such as human capital, natural capital, social capital and financial capital can facilitate the achievement of the goal (yield optimization).

These can help to improve agricultural systems, management of climate risk and agricultural intensification. Therefore, the CF above carries the salient aspects to be dealt in the discussion of this paper, and eventually to insinuate the best ways of positive advancing in agricultural sector.

3.2.2 Data Collection and Sampling Design

Household surveys, informative interviews, physical observations, group discussions and literature reviews were the main approaches for data collection in the study area where 400 respondents were randomly sampled (Humphrey and Kimberly 2007). Purposive sampling was employed to sample Kongwa among the semi-arid districts of Tanzania mainly based on the frequency of food shortage and other physical aspects (URT 2007).

The same approach was used to select the two village and informative interviewers (Cramb *et al*., 2004). Further, simple random sampling was used to select the 400 households during survey (Kothari 2004; Brown 2006). Data related to crop yields of the major food crops (maize, sorghum and millet) were mainly collected from the Ministry of Agriculture, Livestock and Fishery (MALF) and Kongwa District Agricultural and Livestock Development Officer (DALDO) while climate data were gathered form the Kinyasungwe meteorological station located in the study area.

Moreover, the National Agricultural, Environmental, Water and Population Policies were consulted to gasp their implications toward food security. Here interviews were conducted with policy experts and agricultural officers at both ministerial and district levels respectively. In addition, publication materials such as books, journal papers, original scientific work, government reports and academic dissertation just to mention a few were adequately consulted during review to identify and bridge up the gap basing on the study’s objective. The household questionnaires for this survey were constructed and designed purposely to grasp important information that answer the research questions (Saunders, 2011). The main questions included: socio-economic characteristics of the household/respondents; household major economic activities; main types of crops produced; and farmers’ perceptions on food security and agricultural policy.

Therefore, the questionnaire encompassed the following sections: (i) The appraisal scenario where researchers introduced to respondents the rationale of the survey; (ii) The status of agricultural production and its influence to food security; (iii) Key agricultural aspects that are addressed in Agricultural Policy; (iv) If they are aware of policy issues or not and why? (v) Influence of global environmental change to agriculture; (vi) The role of the household head in ensuring food security. In between the reconnaissance survey and actual survey data collection, research assistants were trained on the appropriate way to administer questions. The important aspects of the questionnaire were introduced to them.

Quantitative data were gathered using structured questionnaires as the main tool. The structured questionnaire covered questions on main agricultural practices, crops produced, amount of crop yields, implication of the obtained yields to food security, what is the major cause for crop yields, what are the existing strategies to curb food shortage, what is the way forward to solving the problem. Besides, climate data were collected in the meteorological stations in the study area.

3.2.3 Data Analyses

Crops data were analyzed from MALF and the study area basing on tons per hectare to obtain the actual production trends. If we could use the total yields, we could not get the actual results, because the total yields might increase due to expansion of farms or other factors. This could show increased total yields while the actual production (tn ha^{-1}) has decreased. The Mann-Kendall Test and Microsoft excel (window 13) were important software for quantitative data analyses. These analyses established the productions trend of each crop i.e., maize, sorghum and millet from 1980 to 2015. The Mann-Kendall Test was also employed to analyze the mean annual rainfall of the study area. The data from questionnaire survey were also independently analyzed. Quantitative data from the 400 questionnaires were coded and cleaned for final analyses.

Statistical Package for Social Sciences (SPSS) version 20 was employed to analyze quantitative data. We carried out analysis to acquire frequency responses from farmers who expressed their understanding on various research aspects. From this, we also established some tables to present the results. In addition, we employed theme content methods to analyze qualitative data that were mainly collected through interview and group discussion.

3.3 Results

The overall results indicated that maize yields had high total quantity compared to sorghum and millet (Figure 3.2). In good years it accounted to 90,000 tn while sorghum and millet trailed to 4000 tn and 1000 tn respectively (Figure 3.2).

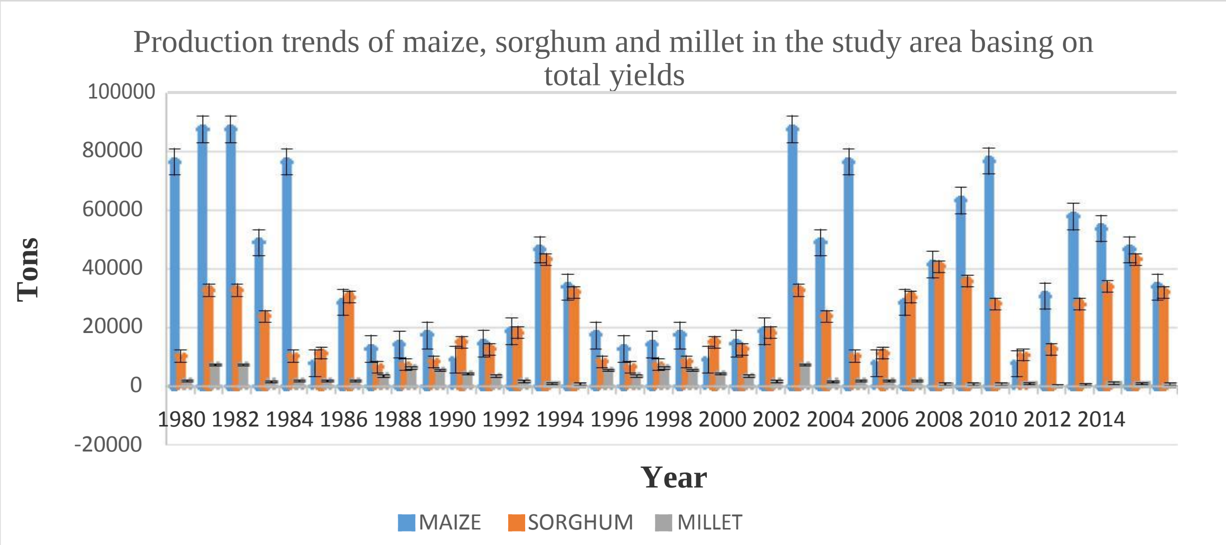

Figure 3.2: Trend of maize, sorghum and millet production in the study area

Source: Field Survey Data, 2016

Yields per hectare were analysed to determine the actual seasonal variability (Figures 3.2–3.5). The results from such analysis showed that maize, sorghum and millet yields significantly decreased (P <0.05) at R^2=0.40, 0.35 and 0.11 respectively (Figures 3.2–3.5). In additional, 80% of the interviewed farmers were in agreement with the results (See Table 3.1). They further mentioned extreme drought as the significant cause of the vain. Moreover, a number of government reports such as the National Adaptation Program of Action (NAPA) and the review of food and agricultural policies of 2014 had similar observation on the same (URT 2007; 2014). The prolific elucidation of each crop is done in the following sections below.

3.3.1 Trend of Maize Production

The production trend of maize has been decreasing from 1980 to 2015 at R^2 = 0.40 (See Figure 3.3). The overall quantitative decrease ranged from 2.2 to 1.5 ton per hectare (3% per year). In addition, over 80% of the respondents had similar observation (See Table 3.1; Mkonda and He 2017b).

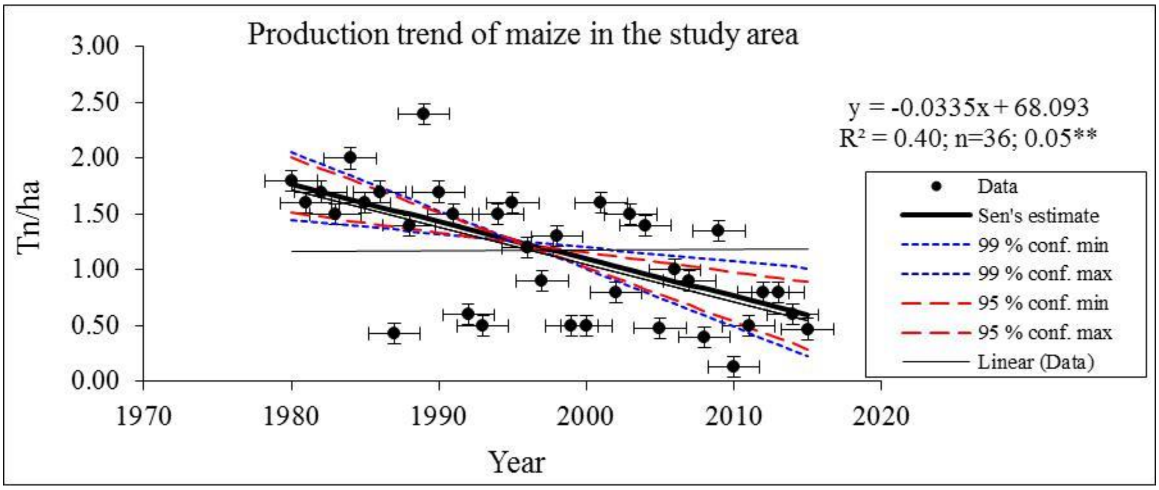

Figure 3.3: Trend of maize production (as a ratio of ton per hectare) in the study area

Source: Field Survey Data, 2016

They further vetted extreme climate variability as the major cause of the crisis. The studies by Paavola (2008) and Msongaleli *et al*. (2013) pointed out in favor of the farmers' observation. In addition, the results from interviews cemented on the same. It is discernible that maize is the main food crop throughout levels from the local to the national as account for over 70% of the cereal food requirement in the country (URT 2013). The crop is also a staple food in most African communities in Kenya, South Sudan, Burundi, Mali, Ghana, Ivory Coast, Nigeria, Malawi and Democratic Republic of Congo (Mmbando *et al*., 2015; Conceição, *et al*., 2016; Cornia *et al*., 2016).

To be consistent, the same question were asked to two elders from different villages and they gave similar response that maize production has been decreasing in their areas. They further explained that the unpredictable, erratic and change of onset dates of rainfall have been a major cause of the vain. They gave life experiences that, under rain fed agriculture, even the fertile soils do not give expected yields.

3.3.2 Trend of Sorghum Production

Sorghum was among the dominant crops in the study area (semi-arid) produced by the majority of the farmers. It was among the drought resistant crops, and therefore, its resilience to climate change impacts was a bit high (Mkonda and He 2017b).

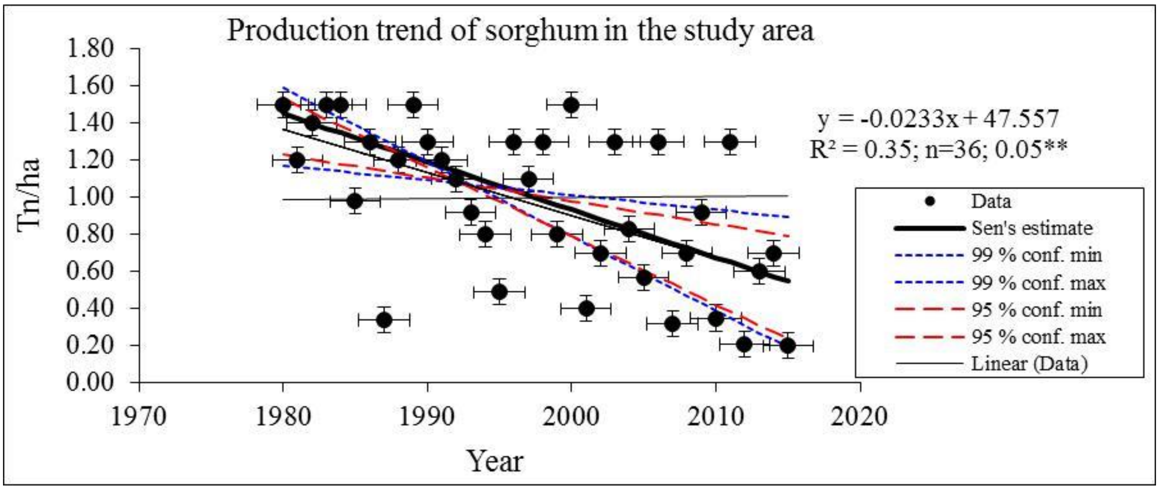

Figure 3.4: Trend of sorghum production (as a ratio of production per hectare) in the study area

Source: Field Survey Data, 2016

Despite this resilience, its production has been decreasing at R^2 = 0.35 (Figure 3.4). The overall quantitative decrease ranged from 1.4 to 0.5 ton per hectare (2.5% per annum). In addition, more than 80% of respondents had agreement with these results (See Table 3.1). They mostly pointed at excessive droughts and soils infertility as the major causes of yield decline in their areas. On such premises, they asserted that, the former is due to climate change impacts while the latter is amplified by continuous cultivation without soil fertilizations. The studies by Lobell and Field (2007) also had similar observation with the results of the present study.

3.3.3 Trend of Millet Production

Millet has been trivially produced in the area compared to maize and sorghum respectively. Even its production was potentially low compared to maize and sorghum. Its production trend has been decreasing at a non-significant rate ($P > 0.05$) at R^2 = 0.11

as seen in Figure 3.5. Meanwhile, the rate of yields decline was less compared to maize and sorghum respectively (Mkonda and He 2017b). This is because most millet cultivars are resistant to droughts and other environmental stresses. Furthermore, this is confirmed by the results from informative interviews, discussion and physical observation (See Table 3.1).

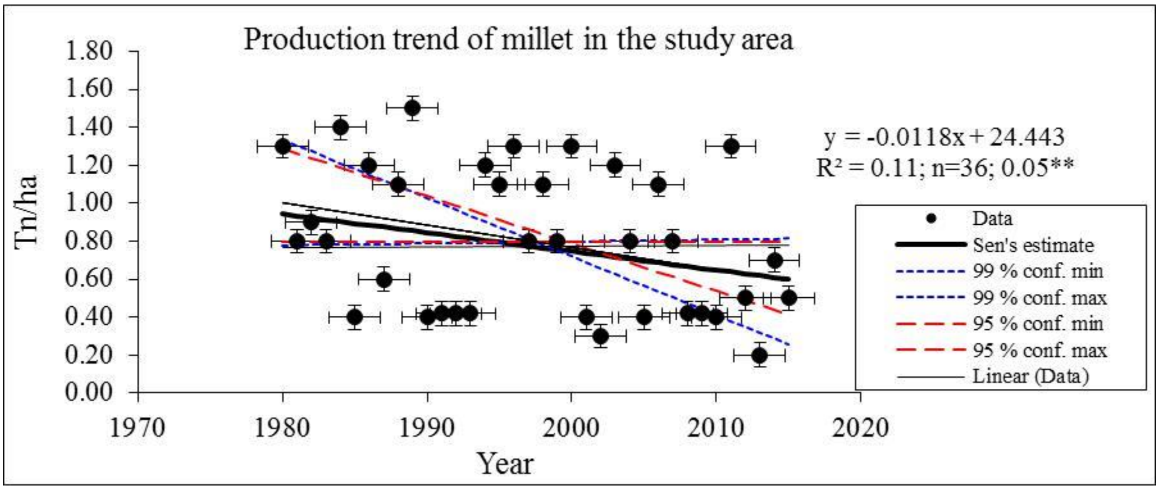

Figure 3.5: Trend of millet production (as a ratio of production per hectare) in the study area

Source: Field Survey Data, 2016

In addition, through physical observation, it was noticed that most of the farmers were poor and had no resilience to adjust or recover from climate change impacts and other environmental stress. Under such a condition, the livelihood options are too limited. In general, the temporal fluctuation and decrease of yields had caused frequent food shortage, hunger and economic turbulence. The prevalence of frequent hunger brings about malnutrition and other allied diseases especially to children less than five years. In schools, the academic progression among the students deteriorates due to starvation. Food shortage had multiple negative impacts to social, economic, academic and political aspects, just to list a few. Therefore, proactive measures need to be taken by government and other development partners to build capacity among the farmers.

3.3.4 Response from Farmers

The results from data analyses from the Ministry of Agriculture, Livestock and Fisheries (MALF) had association with those from the respondents (Table 3.1). Overall, most farmers perceived that the production trend of the major food crop has been unsatisfactory and thus, has posed frequent food shortage (insecurity) and exacerbated poverty (Mkonda and He 2017b).

Table 3.1 Responses (Yes) on important aspects of agriculture and policy

Adaptation Activities	Mnyakongo (n = 200)	Ugogoni (n = 200)	Average (n = 400)
Average maize yields per HH (<500 kg)	160	151	155.5
Average sorghum yields per HH (<500 kg)	172	177	174.5
Average millet yields per HH (<500 kg)	172	165	168.5
Maize yields not sufficient for food	185	188	16.5
Sorghum yields not sufficient for food	175	176	175.5
Millet yields not sufficient for food	180	191	185.5
Awareness on Food Policy	21	16	18.5
Unfair distribution of agricultural inputs	160	155	157.5
Willingness to address climate impacts	170	165	167.5

Source: Field Data Survey, 2016

The results in Table 3.1 above explore the actual situation of the farmers in the study areas and other related regions with similar biophysical characteristics. Although the majority respondents had basic education, they had a wide understanding on their locality more especially on the socio-economic and biophysical change of their local condition.

3.3.5 Food Security

According to FAO (2009; 2011 and 2012) food security has got three major pillars namely (i) Food availability: refers to sufficient quantities of food available on a consistent basis; (ii) Food access: refers to having sufficient resources to obtain appropriate foods for a nutritious diet; (iii) Food use which refers to appropriate use based on knowledge of basic nutrition and care, as well as adequate water and sanitation.

Moreover, food insecure households refer to being not able, at some time during the year, to provide adequate food for one or more household members due to lack of resources whilst a very low food secure households refer disruption of normal eating patterns of some household members and their food intake reduced below levels they considered appropriate.

Self Sufficient Ratio (SSR) refers to the situation where food availability is compared to food requirement to determine the food deficit (URT 2009; 2014). It is expressed as SSR of the area = Production/Requirement × 100%. Basing on these concepts, the SSR was calculated to determine the food security in the area. The crops yield data from the Ministry of Agriculture and Kongwa District (District Agricultural and Livestock Development) were used to calculate it. Consideration was on the availability, accessibility and use of food.

In the study area, the SSR varied depending on the production levels of food crops. The calculation hereunder has given mathematical explanation of this concept. The results from group discussion, informative interviews and physical observation gave additional information on the same that was useful to make inference of the study. Table 3.2 below gives evidence that the yields from food production have not been enough for a couple of years.

Table 3.2: Production trends (tn) of maize, sorghum and millet in the study area (1996–2015)

Year	Maize		Sorghum		Millet		Total	
	Produced	Required	Produced	Required	Produced	Required	Produced	Required
1996	12,800	17,500	6500	9700	3460	4500	22,760	31,700
1997	14,200	18,400	7300	12,000	6300	9300	27,800	39,700
1998	17,400	23,900	8400	13,000	5400	8500	31,200	45,400
1999	9200	23,500	15,100	17,000	4200	6800	28,500	47,300
2000	14,600	17,900	12,600	18,000	3400	4390	30,600	40,290
2001	18,800	25,900	18,300	23,900	1670	2300	38,770	52,100
2002	95,600	138,000	32,800	52,000	7200	9800	135,600	199,800
2003	48,990	68,800	23,900	34,000	1600	2000	74,490	104,800
2004	119,300	136,000	10,320	13,500	1820	2300	131,440	151,800
2005	79,300	99,600	11,200	14,900	1850	2500	20,980	117,000
2006	28,600	35,000	30,400	42,900	1830	2400	60,830	80,300
2007	41,500	68,000	40,820	65,000	710	1100	83,030	134,100
2008	63,313	89,000	35,818	45,800	768	1080	99,899	135,880
2009	76,867	94,000	28,179	34,590	826	1300	105,872	129,890
2010	77,560	89,000	10,706	13,500	974	1400	19,436	103,900
2011	30,741	58,000	12,617	15,609	212	390	43,570	73,999
2012	57,834	89,000	28,018	32,000	643	890	86,495	121,643
2013	53,831	85,000	34,019	40,000	1017	1350	88,868	126,350
2014	46,582	65,900	43,375	54,000	994	1300	90,952.25	121,200
2015	33,848	40,000	21,067	34,000	734.5	1681.563	55,649.5	75,681.5

Source: Ministry of Agriculture, Livestock and Fisheries-MALF (URT 2013)

3.3.6 Calculation of Food Self-Sufficient Ratio and its Implications to Food Security

Self Sufficient Ratio (SSR) refers to the situation where food availability is compared to food requirement to determine the food deficit (URT 2014; 2009). It is expressed as SSR of the area = Production / Requirement X 100%. In the study area, the SSR had a temporal variation depending on the production levels of food crops. The calculation below in this section has given mathematical explanation of this concept. The results from group discussion, informative interviews and physical observation gave empirical situation that meant food security. It is that, out of 12 months of the year, they can survive with their farm yields for less than 6 months.

Table 3.2 below gives evidence that the yields from food crops have not been satisfactory for a couple of years. In general, it can be concluded that the production of the three crops has not been enough for food security in the area.

Calculation;

Basing on the information from the District Agricultural and Livestock Development Officer (DALDO),

(i) The total production of staple food crops (maize, sorghum and millet (2015) = 55649500 kg.

(ii) The annual food requirement was 75681563.75. This figure was obtained through the following procedure;

-The number of people (especially adults) in the study area is 318,995.

- According to FAO (2012), the daily requirement of food (particularly starch) per person is 0.65kg. Therefore, the daily starch requirement of the people in the study area:

=Total Population X 0.65kg

Hence, 318,995X 0.65=207346.75 kg (per day)

Since, 207346.75kg is the daily food (starch) requirement in the area, then the annual food (starch) requirement for the total population in the study area is about 75733400 kg. Mathematically, 207346.75kg X 365.25 (days) =75733400.44 kg (yearly food requirement).

Since SSR = Production / Requirement X 100%

Thus,

SSR = (55649500 kg /75733400.4375kg) X 100% = 73.4%

Therefore, the implications of 73.4%% as the SSR in the study area, is that there is food shortage of 26.52% in the study area. Thus, out of 365.25 days, there are about 85 days (roughly 3 months) a year, in which people totally have no food, they are extremely food insecure. As a result, they therefore severely starve and some die. The death may occur in the name of other diseases related to malnutrition and starvation.

These findings were then supported by household heads where over 70% of the respondents informed that they have reduced the number of meals from three to two or one as a coping mechanism. Some adjusted to the situation by eating wild foods (fruits, roots etc.). For any reasons, this problem is significant and is more pronounced to the poorest households. The researchers of this study also confirmed on the severity of the problem and it was clear that the majority were living under severe starvation.

The results from analysis showed that there is a strong correlation between the prevalence of food insecurity and the impacts of climate change and variability in the study (P <0.05). Despite of the existence of some adaptation and coping strategies, yet food insecurity is an acute challenge in the area. Actually, one needs to be more proactive in proposing adaptation measures to curb the vain. Otherwise, we cannot further progress in terms of development and other community welfare.

3.3.7 Policy Framework

National Agriculture Policy (2013) is the leading instrument to spearhead agricultural industry in the country. Besides, other relevant sectoral policy that work closer to NAP include, but not limited to: National Environmental Policy (1997), National Water Policy (2002) and National Population Policy (2006). These government instruments collectively aim to elevate the living standard of the people through sustainable utilization of environmental resources (URT 1997; 2002; 2006; 2013. This is stipulated in Agricultural Policy (in Sections 3.1.1, 3.4.1, 3.5.1 and 3.12.1), Water Policy (in Section 2.3), Population Policy (in Section 4.9), and Environmental Policy (in Section 4.6).

NAP indicates that, the country has an arable land around 44 million hectares with diverse water resources ranging from big lakes to numerous rivers, and wetland ecosystems (2013). However, only 10.8 million hectares (24%) of this arable land has been under agriculture. Further, this percent is greatly dominated by small scale farming which always yields less harvest around 3 tn/ha; this is contrary to the productivity potential of 6–7.5 tn/ha (URT 2013). Besides, the irrigation potential is also poorly harnessed as less than 4% of the irrigable land has been exploited. Thus, compelling efforts are needed to expand the production systems of agriculture in the country.

3.4 Discussion

3.4.1 Crop Yields

The results from analyses indicated that yields from both small and medium scale farming had temporal fluctuation (Figures 3.2–3.5). For a duration of about 35 years; the production trends for maize, sorghum and millet have been declining significantly at R^2 = 0.40, 0.35 and 0.11 respectively. This is in agreement with Lobell *et al.* (2009) and Lobell and Field (2007). This trend has also been observed in other African countries such as Malawi, Kenya, South Africa, Mali and Niger (Conceição et al., 2016; Cornia *et al*., 2016).

In the context of sub-Sahara Africa, the region has diverse climate, politics and historical background that significantly contribute to low yields and environmental unsustainability (FAO 2012; Neufeldt, *et al*., 2013; Harvey *et al*., 2014; Lipton *et al*., 2012; 2013). The countries located in arid and semi-arid agro-ecological zone are more vulnerable than those with moderate climate. Besides, the intra-climate variations within each country pose diverse magnitude of the impacts (Sen 1993; 1999; Lobell *et al*., 2010; Eriksen and Noess, 2003; Mkonda and He 2017b).

Among the major aspects that hinder crop production in the study area is climate change impacts. This is evidenced by the decreasing trend of the mean annual rainfall (See Chapter 4). Again, there has been a positive correlation between the production trend of crops and rainfall variability (Figures 3.2-3.5). Despite of adopting some drought resistant crops cultivars, the yields remained insignificant. Maize appeared to be more vulnerable to environmental stress than sorghum and millet as it significantly declined than others (Figure 3.2 &3.3).

In addition, millet was resistant to drought as it insignificantly declined than maize and sorghum (Figure 3.5). This resistance was attributed by the bulrush and finger millet varieties which are predominantly produced in the area. The production trend from 1980 to 2015 was fairly inconsistence and thus, it brought about socio-economic turbulence to the farmers. Further, the results revealed that there were significance difference (P <0.05) between the low and medium class and/or above on the capacity to produce or/and recover from environmental stress. This was evidenced by the crop failure and increased vulnerability (Tables 3.1 and 3.2). In this case, the poor farmers were more vulnerable than the wealthy class.

Previously, Tanzanian agriculture was meant to provide food for survival and other socio-economic welfare to farmers. However, the current situation is quite different because the obtained yields is no longer helpful to the majority farmers (i.e., smallholder farmers) even for a quarter of a year i.e., especially during bad years.

In geomorphological aspect, highland areas had fewer yields than the lowland. Quantitatively, the low land farms produced about two times than the counterpart side. This appeared to be attributed by high soil moisture content in the lowland than in the highland). Similarly, the lowland appeared to receive organic materials through run-off which eventually decomposed into organic matter (useful for crops production) than the highlands did. These could be among the reasons for the yields differences between the two lands.

Another novel aspect in the analyses indicated that, among other things, excessive drought and poor soil management were the major reasons for crop failure in the area. In this aspect, climate change impacts, poor soil and inappropriate agronomic practices were significantly implicated on the same (URT, 2007). In addition, Rowhani *et al*. (2011) informed that 20% increase in intra-seasonal precipitation variability reduces agricultural yields by 4.2%, 7.2%, and 7.6% respectively for maize, sorghum, and rice which are the major food crops in Tanzania.

Likewise, Neufeldt *et al*. (2013) and Harvey *et al*. (2014) supported that soil organic management practices such as application of animal manure, little tillage and soil cover increase have significant contribution to increased crops yield and thus, they need to be adopted in agricultural production. These practices eventually optimize food security, the resilience/adaptive capacity of farmers and mitigation of climate change by sequestering carbon in biomass and soils and/or reducing greenhouse gases emissions.

Poor yields of the major food crops brought socio-economic repercussion to the community. It was revealed that, despite the major aim of crop production being for food, farmers also aimed to sell (cash) the excess yields (Table 3.3); the target was not met due to low and seasonal variability of yields.

Table 3.3. Percentage of utility among the key crops in the study area

Crop	Food	Cash	Food & Cash	Total (%)
Millet	60	1.3	38.7	100
Maize	80	0	20	100
Sorghum	65	5	30	100
Average (*n* = 400)	68.3	2.1	29.5	100

Source: Field Survey Data, 2016

In this regards, seasonal variability of crop yields (i.e., decrease) caused frequent food shortage, hunger and economic turbulence especially in most vulnerable areas. The prevalence of frequent hunger and undernourishment further brought about malnutrition and other allied diseases especially to children less than five years. On top of that, the academic progress among the primary and secondary school learners also deteriorates due to starvation.

In all, shortage had multiple negative impacts to social, economic, academic and political aspects. Physical observation and discussions indicated that most farmers were weak to cope or recover from the posed environmental stress. Therefore, the government and other development partners should take proactive measures to build socio-economic capacity of these smallholder farmers.

3.4.2 Status of Food Security

The calculation in Section 3.6 above reveals that, out of 365 days, SSR of food was about 70% thus making 30% food insecure. This means, overall out of 365 days, there were about 85 days (roughly 3 months) a year in which people had no food access;

hence, they were food insecure. However, this quantitative food shortage is not necessarily in the continuum days and months, but it reflects the general magnitude of food shortage in the area. By all means, this situation leads to abject malnutrition and death to people especially to children under 5 years. Despite of having no in-depth statistics, the Ministry of Heath approximates to about 5% of the children have been dying of that.

Further, abject poverty limited some farmers to access food from other areas (i.e., districts). The destitute mostly relied on remittances, government aids, religious institutions and other development partners. Unfortunately, it appears that always the destitute are many than the available capacity to feed.

These results were also observed by UN agencies like FAO, WHO and UNDP which categorized Sub-Sahara Africa as the most affected and vulnerable region to global environmental change while IPCC (2014) grouped Tanzania among the 13 most affected and vulnerable countries by climate change in the world. Thus, the present study and the findings from other studies herewith, justify what is exactly happening on the ground.

Besides, it appeared that old people were more vulnerable to the stressed environment and food shortage than the working class (15–64 years) because they were socio-economically weak to adjust or cope with the incumbent dreadful conditions. During hunger, they could not migrate to turban areas to seek employment as young people always do. It was further noticed that, despite of being vulnerable, some of these elders had responsibility of taking care of their grandchildren whose biological parents either died or were divorce. For example, 80 years old man, expressed his deep feeling to the researcher that he has been living alone after the death of his wife and children for a couple of years ago.

Despite of that situation, he was obliged to engage in crop production using hand hoe to earn his daily bread from the farm. He gave long-life experience in agriculture and declared that, the production of the major food crop had a tremendous downfall. Finally, he concluded that, compelling efforts from the government and development partners are cordially needed to curb the situation.

This kind of vulnerability was also observed in Malawi and Niger by Ricker-Gilbert and Jones (2015) and in most sub-Sahara Africa by UNDP (2012) and Conceição *et al*. (2016). The semi-arid arid and other vulnerable ecosystems appeared to be mostly impacted. The western African countries like Mali, Niger and Ivory Coast were good example in this vain (Higgins *et al*., 2015).

A study by Rowhani *et al*. (2011) and Msongaleli *et al*. (2015) on the impacts of climate change on cereal crops observed that crop failure is mostly caused by climate variability. They also indicated that, poor people are adversely impacted than the wealthy who are resilient to the dreadful condition. Hence, wherever impact happens in the community, it is the weak people who mostly suffer the consequences and thus, policy makers and planners have to have a third eye on these destitute and think big on the same.

Therefore, it should be understandable that, to improve food security, social welfare and economic development we need to be more innovative in the production systems and more preferably the dissemination of research finding on crops, fertilizations and possible irrigation. Otherwise, to achieve economic development while struggling for food security will not be fruitful.

3.4.3 Policy Implications

Agricultural policy of 2013 which is responsible for food production has stipulated various aspects that meant to improve crop production. This stipulation has also been done by other related policies such as Environmental Policy 1997, Water Policy and Land Policy. For example, Section 1.3 of the Agricultural Policy outlines challenges that are mostly directed to last users. To accord such a problem, the establishment of strong institutions is inevitable.

This also includes legal organs with well stipulated laws, Acts, regulations and procedures. However, the interpretations of these laws, regulation and Acts should be clear. Despite of these stipulations, farmers are still facing frequent food shortages. This is attributed by the increased factors that influence the vulnerability of the farmers (Table 1.1 in Chapter One).

3.5 Conclusion

It is evident that the production trend of maize, sorghum and millet have been declining significantly and thus, causing food shortage and insecurity in the area. Since 1980–2015 there has been a decline in yields for maize, sorghum and millet. This situation has caused frequent food shortages and famine. In other words, famine has not yet been curbed because the production is still not promising. Among other things, agricultural policy has not well addressed the problems especially those emanating from global environmental change.

Under such a condition, the farmers, especially old people (the dependence class) have been more vulnerable to famine than the rich class as they have limited adaptation options and weak recovery from the impacts. The results from the calculations in Section 3.6 above, have provided empirical results and interpretation that the area is food insecure and thus, this ultimately imply that the poor suffer the consequences.

Despite the NAP 2013 and its allied policies aiming to ensure food security in the country, the crisis still persist and thus, most farmers who constitute agricultural industry in the country are in mess. Their vulnerability arises mostly from their poor endowments (less than 2 ha under cultivation) and entitlement failure (famine and hunger). Therefore, there is a need to revise agricultural policy by accommodating new needs of farmers to build socio-economic capacity, optimize production and upsurge their livelihoods along with increasing the country's Gross Domestic Product (GDP).

Hereunder, are some potential aspects that can be accommodated in the policy to build capacity of the farmers in both semi-arid agro-ecological zones and the whole country.

a. Thorough assessment should be done countrywide to assess the differential requirements of the people. This should mainly focus on the smallholders located in the marginalized areas.
b. Quantification of needs assessment across different agro-ecological zones, i.e., inputs.
c. Timely supply of the agricultural inputs i.e., fertilizers, seeds etc.

d. Proper budgeting and timely provision of help especially during food shortage instead of making long logistics until some of the victims die.
e. There should be substantial guidance on the proper adaptations to climate change impacts as they vary over agro-ecological zones.
f. The Government should put her hand in agriculture by not only providing subsidies but also having some farms as demonstration. This will oust the dominant dogma in the country that agriculture is for the people with no livelihood options. As well, this will help to increase food reserves through surplus production.
g. Therefore, there is a need to make compelling efforts to ensure surplus food production and sustainable food security is in the country. After that, the country would plan for serious industrialization to make an economically stable country

Chapter Four: Climate Variability and Crop Yields Synergies in a Tanzania's Semi-arid Agro-Ecological Zone

4.1 Introduction

In this era of climate change, it is worthwhile to assess the effects of climate variability on agriculture and environment in order to design proper adaptation and mitigation measures that improve resilience (IPCC 2014; Serdeczny *et al*., 2017). The Intergovernmental Panel on Climate Change (IPCC) has confirmed that there is substantial evidence that the mean and extremes of climate variables have been changing in the recent decades, and that rising atmospheric greenhouse gas concentrations could cause the trends of the climate variables to intensify in the coming decades (IPCC 2014).

Ahmed *et al*. (2011) found that rainfall has significantly decreased in Tanzania especially in the recent years and is further expected to decrease by the mid of this century. In addition, Challinor *et al*. (2007), warned of the increased vulnerability of the rain fed agriculture due to the changing climate. Under such situation, Lobell *et al*. (2008) realized the importance of studying and proposing ways of reducing the vulnerability among the rural communities in most developing countries, because their livelihoods depend on rain fed agriculture. Likewise, this vulnerability has implications to agricultural production and the ecosystems services as farmers may degrade the environmental resources when trying to cope with the associated challenge (Nyong *et al*., 2007; Speranza et al., 2009; Rao *et al*., 2011; Muller and Shackleton 2014).

So far, there is substantial literature examining the effects of climate change on agriculture and ecosystems in various developing countries. National Adaptation Plan of Action (NAPA) and Tanzanians National Strategy for Growth and Reduction of Poverty identified droughts and floods as among the primary threats to agricultural productivity and vulnerability to poverty in the country (URT 2007; 2005). In addition, Paavola (2008), Rowhani *et al*. (2011) and Msongaleli *et al*. (2015) confirmed on the decreasing rainfall and insisted that this scenario has significant implications for crop yields.

Further, Lobell *et al*. (2008) and FAO (2009) emphasized that rain fed agriculture will be more susceptible to any further intensification of climate change.

Similarly, Challinor *et al*. (2007) confirmed that climate change and variability has significantly affected food crops especially cereals like maize, rice, sorghum and millet. In addition, Paavola (2008), Mongi *et al*. (2010), Mkonda (2011) and Yanda (2015) affirmed that there is a positive correlation between climate change and crop yields under rain fed scenario. Rowhani *et al*. (2011) specified that 20% increase in intra-seasonal precipitation variability reduces agricultural yields by 4.2%, 7.2% and 7.6% respectively for maize, sorghum and rice which are the major food crops in Tanzania.

Consequently, he projected that by 2050 climate change and variability will affect crop yields in Tanzania by 3.6%, 8.9%, and 28.6% for maize, sorghum and rice respectively. Kangalawe (2016), further asserted that impacts of climate change have significantly dried water sources such as wetland and thus, narrowing the threshold of community livelihoods. Other scholars have warned on the increased degradation and vulnerability of the ecosystems due to increased incidences of droughts and temperature (Paavola 2008; Muller and Shackleton, 2014).

Although the science of assessing the impacts of climate changes on agriculture (crop yields) and ecosystems in various agro-ecological zones is progressing rapidly, a variety of knowledge gaps still exist. Most of these studies have paid little attention on the analyses of semi-arid agro-ecological zone where most peoples' livelihood is considerably susceptible due to insufficient yields and abject poverty. Thus, the present study aimed to advance from where other studies ended.

Since the vulnerability posed by climate change is progressing high; compelling adaptation measures for either adjusting or healing the stress are inevitably required to curb the situation. By doing so, the livelihoods of over 80% smallholders will be rescued (Mkonda & He, 2017b). The study will further enable planners and policy makers to propose robust policies and sound tools with new techniques of curbing the impacts of the increasingly changing climate at both local and global scales which mostly affect the smallholder farmers in developing countries especially the sub-Saharan Africa.

Essentially, this paper aims at establishing the correlation between the trends of climate variability and that of crop yields in the semi-arid agro ecological zone of Tanzania (focusing Kongwa District). Further, it aims to intensify the adaptation measures that would increase crop production in the area. These objectives are tackled through the following research questions: a) What are the trends of rainfall and temperature in the area? b) What is the production trend of the major food crops in the area? c) Is there any substantial correlation between the trends of these climate variables and that of crop yields? d) What are non-climate factors that seem to affect crop yields? e) What is the contribution of the present study to smallholder adaptation in the area? In this aspect, climate variables were rainfall and temperature while maize, sorghum and millet were the selected crops.

These crops were selected because they are staple food crops contributing to about 90% of the food security in the area (URT 2014; 2013; 2007). The current Agricultural Policy advocates the adoption of adaptation strategies; however, it has not exhausted solving the problems. Therefore, this study suggests the best practices that can optimize yields, food security and socio-economic welfare especially in the face of climate change.

4.2 Methodology

4.2.1 Data Collection

Temporal rainfall and temperature data (1980-2015) were collected from the Tanzania Meteorological Agency (TMA) and Kinyasungwe, the meteorological station in the study area. Yields data for maize, sorghum, and millet (1980-2015) were collected from Kongwa District Agricultural and Livestock Development Officer and the Ministry of Agriculture, Livestock and Fishery.

Besides, ecological issues (i.e. degradation, droughts etc.) were solicited and determined at field level and from the literature. A total of 400 questionnaires were collected from household heads of smallholders (farmer/livestock households. The questionnaires involved both closed and open questions (See Table 1.4 in Chapter 1). About 10% of the total households in each community were sampled (Table 1) and has also been pointed by Saunders (2011). The household lists were obtained from village government leaders in the study area.

Participatory Rural Appraisal method (PRA) was also used to collect socio-economic data in the area. PRAs include informative interviews, group discussion, and physical observation. The application of the PRA method has been used in various studies to explore perceptions of rural communities on environmental issues that affect their lives (Cramb *et al*., 2004; Brown 2006; Humphrey and Kimberly, 2007). In the present study, the PRA was used to acquire data on climate, yields and environmental changes. One group discussion comprising of 15 people was organized in each village. A total of 20 interviews were conducted with agricultural experts, farmers, livestock keepers and village government leaders (See Table 1.4 in Chapter 1). In this category, a checklist of questions encompassing a wide range of questions regarding the main theme of the study was used (*See Appendix A*). Lastly, scientific works such as books, journal papers, government reports and academic dissertations just to mention a few, were sources of secondary data especially during the establishment and development of the study.

4.2.2 Data Analyses

The yields' data collected from the Ministry of Agriculture and from the study area (i.e. from respondents) were parameterized, compared and averaged to acquire a reliable and representative data package. The yields data, and the trend of rainfall and temperature focusing on their mean annual variability using the Mann-Kendall Test (at 95% level of confidence) and Microsoft excel (window 13) (Stern *et al*.,1982) were analysed. The qualitative data from the household surveys were analyzed using theme content methods. Pearson's Moment correlation coefficient and regression analyses were used to compare the trends of rainfall and temperature variability versus crop yields, and extrapolate the future correlations (McCullagh, 1974). P-values less than 0.05 were supposed to be statistically significant ($P < 0.05$). In addition, a conceptual framework (Figure 4.4) was established to portray the correlation among the salient aspects of the study.

4.3 Results

The majority of respondents agreed that climate variability is a true phenomenon and has been affecting their livelihoods significantly (Mkonda and He 2017a). Table 1.3 (in chapter one) presents the demographic characteristics of the household heads. Most of them were male farmers (63%) and female (37%), with different years of farming experiences. Length of farming experience ranged between 10 and 40 years. The demographic characteristics were further used in correlation analysis, to test the relationship between farmer's understanding of climate and their experiences.

The present study also revealed the existing correlation between farmers' experience and the understanding on climate. Table 4.1 indicates that old people (>74 years) were sure at 93.8% that climate variables have been varying/changing compared to 90.4% of 54-73 years, 89.4% of 34-53 years and 80.5% of 18-33yrs respectively.

Table 4.1: Response (based on age) to the question "*Have you noticed climate change*"

Age range	Yes	No	Not sure	Total
18-33	80.5	7.2	12.3	100
34-53	89.4	5.4	5.2	100
54-73	90.4	3.2	6.4	100
≥ 74	93.8	0.0	6.2	100

Source: Field Data Survey, 2016

4.3.1 Climate Variability

The total annual rainfall and mean annual temperature patterns from 1980 to 2015 decreased and increased at R^2 =0.21 and 0.30 respectively (See Figure 4.1). These climate trajectories increased the vulnerability of agricultural systems. The temporal variability of rainfall pattern affected the onset and cessation, intensity, frequency, and amount of rains. The changes of onset dates have had significant impacts to farming calendar to most farmers in the study area while intensity, amount and frequency affected the whole process of agricultural production (Mkonda and He, 2017a).

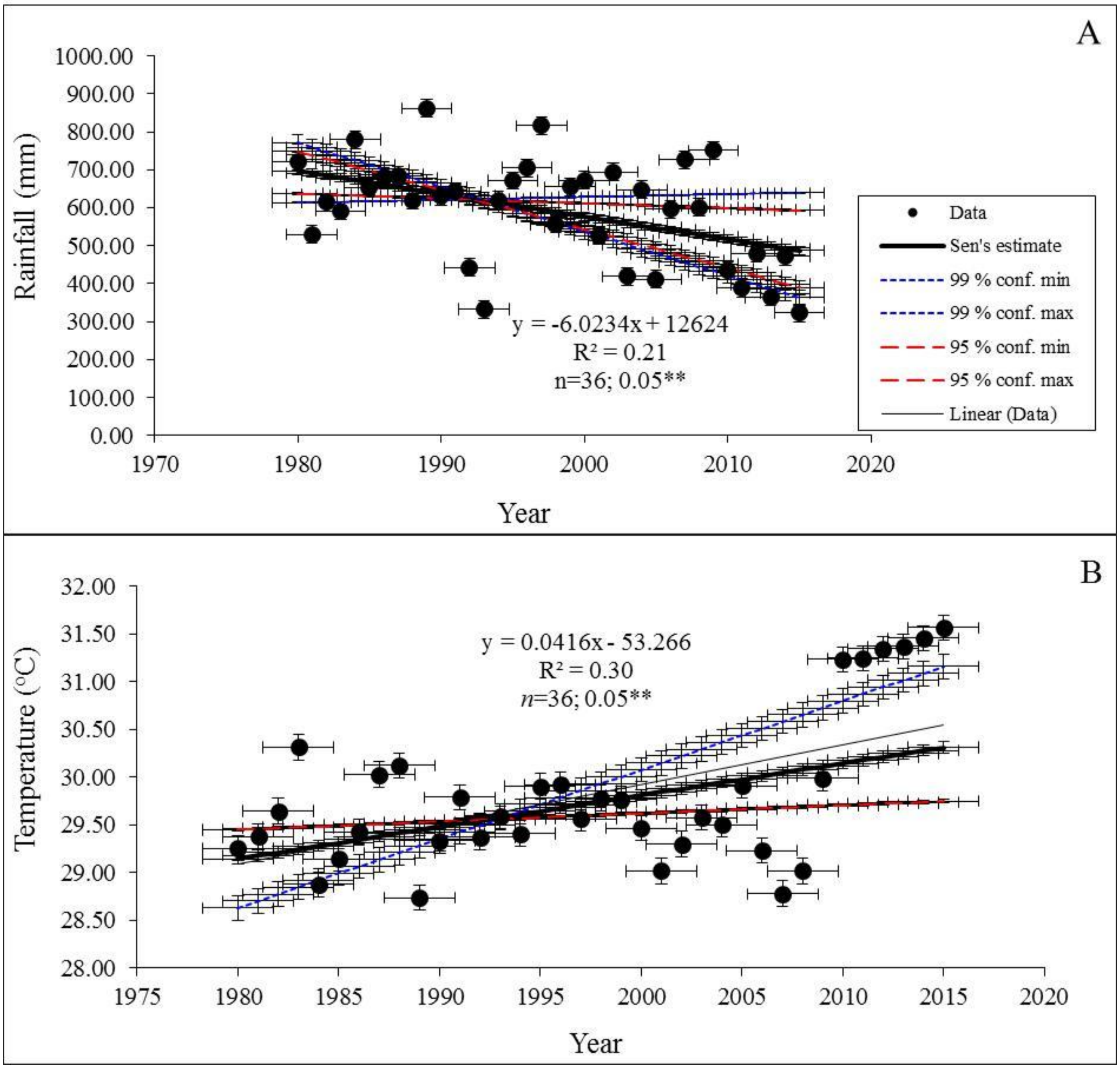

Figure 4.1: Trend of total annual rainfall (A) and mean annual temperature (B) in the study area. **Source:** Field Survey Data, 2016

The results from Figure 4.1 give a general exploration on the trend of rainfall in the study area basing on the annual amount. It displays a wider context on long-term variability that explores the general situation on the ground (Mkonda 2011; Challinor *et al*., 2014). Despite of that, the intra-climatic variation during the growing season (i.e. January, February and March) indicated that; in a duration of 36 years, January had the most fluctuating rainfall trend compared to February and March. About 70% of the respondents also reported that rainfall and temperature have been decreasing and increasing respectively. Table 4.2 reveals that the farmers were assertive that rainfall has been decreasing (70%), fluctuating (25%) and increasing (5%) while temperature has been increasing (65%), fluctuating (25%) and decreasing (10%). Overall, these results indicate that there has been a scenario of decreasing rainfall and increasing temperature in the area.

Table 4.2: Farmers' response (in %) on the change in rainfall and temperature

Village	Rainfall			Temperature		
	Incr.	Decr.	Fluct.	Incr.	Decr.	Fluct.
Mnyakongo	5	65	30	70	5	25
Ugogoni	5	70	25	65	8	27

Abbreviation; Incr, increasing; Decr, decreasing; Fluct, fluctuating

Source: Field Data Survey, 2016

4.3.2 Potential Evapotranspiration

The balance between water supply and release is a determinant factor for ecosystems and agricultural systems in a certain area. The potential evaporation (PE) varies over different agro-ecological zones. For instance, the PE of the semi-arid areas ranges from 700-900 mm per year while rainfall ranges from 400-600 mm per year. This is why the ratio between rainfall (precipitation) and potential evaporation is around 0.05 to 0.65 (IPCC 2014). In other favorable climates and agro-ecological zones such as *alluvial plain*, this ratio increases because of the increase in total annual rainfall. The P/PE is sometimes referred to as aridity index where the total annual precipitation divided by potential evapotranspiration (Zomer *et al*., 2008). The low P/PE value in this semi-arid area has significantly affected the agricultural systems and the environment at large (Elliott *et al*., 2014).

4.3.3 Crop Production

There were significant variations in crop yields among maize, sorghum and millet in the study area (P <0.05). Maize had high yields (in ton per hectare) compared to sorghum and millet (Table 5), but in all crops there was significant yields fluctuation. Generally, about all the crops experienced optimal yields from 1980 to 1980, while meagre yields were observed from 1997 to 2000 and 2011 to 2015 (Table 4.3).

Table 4.3: Crop yields in ton per hectare in Kongwa District from 1980 to 2015

Year	Maize	Sorghum	Millet
1980	1.8	1.3	1.3
1981	1.6	1.2	0.8
1982	1.7	1.4	0.9
1983	1.5	1.5	0.8
1984	2.0	1.5	1.4
1985	1.6	0.9	0.4
1986	1.7	1.3	1.2
1987	1.4	0.3	0.6
1988	1.4	1.2	1.1
1989	2.4	1.5	1.5
1990	1.7	1.3	0.4
1991	1.5	1.2	0.4
1992	0.6	1.1	0.4
1993	0.5	0.9	0.4
1994	1.5	0.8	1.2
1995	1.6	0.5	1.1
1996	1.2	1.3	1.3
1997	0.9	1.1	0.8
1998	1.3	1.3	1.1
1999	0.5	0.8	0.8
2000	0.5	1.5	1.3
2001	1.6	0.4	0.4
2002	0.8	0.7	0.3
2003	1.5	1.3	1.2
2004	1.4	0.8	0.8
2005	0.5	0.6	0.4
2006	1.0	1.3	1.1
2007	0.9	0.3	0.8
2008	0.4	0.7	0.4
2009	1.4	0.9	0.4
2010	0.1	0.4	0.4
2011	0.5	1.3	1.3
2012	0.8	0.2	0.5
2013	0.8	0.6	0.2
2014	0.6	0.7	0.7
2015	0.5	0.2	0.5

*The data from the sources were calculated into ton per hectare. The selected crops in the table are the major food crops in the study area.

Source: The data were collected from Kongwa District (DALDO) and MALF 2016

4.3.4 Impacts of Climate Variability on Agricultural Production i.e. crop yields

4.3.4.1 Rainfall

The results from analyses show that there were strong relationship between rainfall and crop yields in the area (P <0.05). The significant correlation between the rainfall and yields was observed (See Figure 4.2).

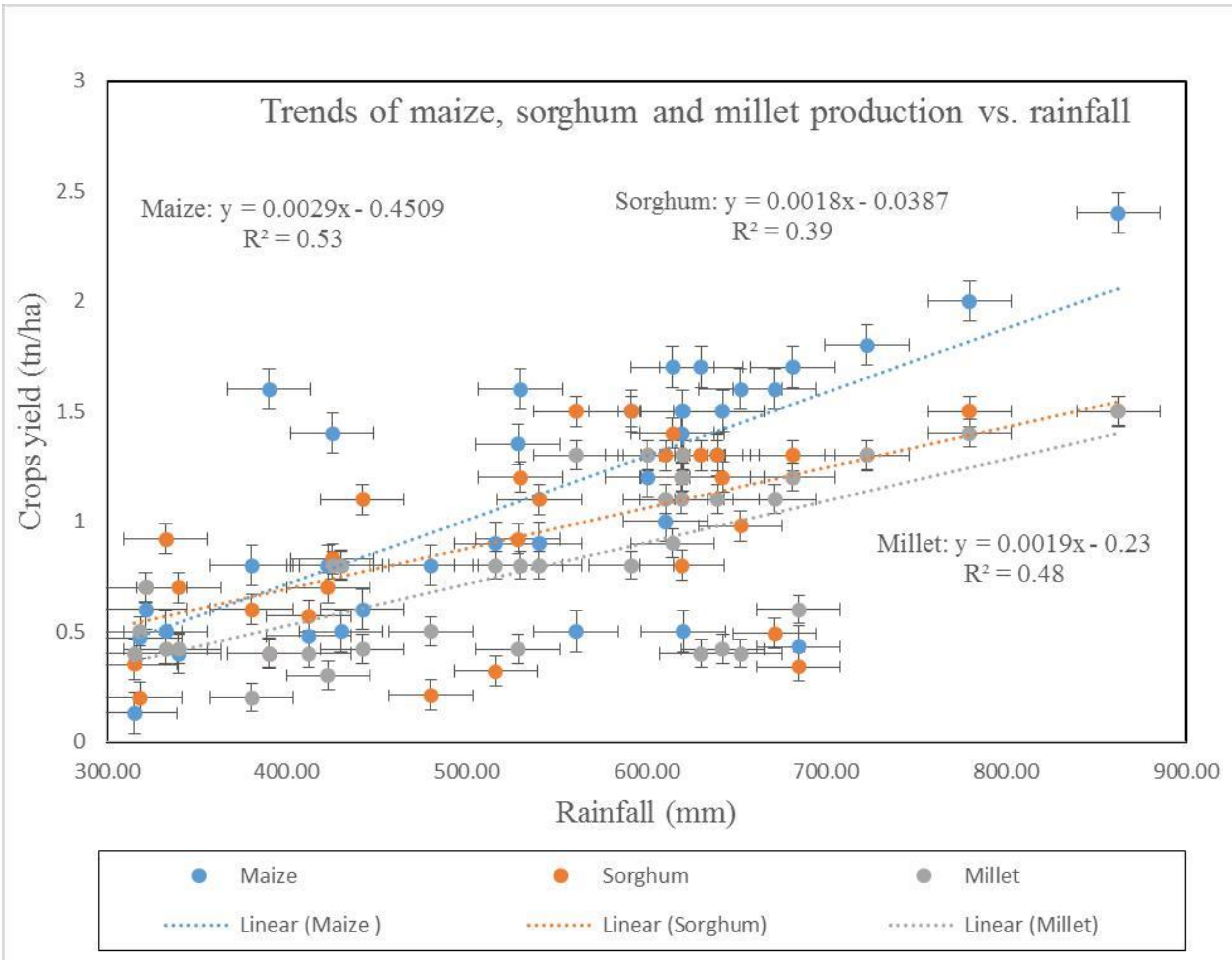

Figure 4.2: Correlation between rainfall and crop yields in the study area

Source: Field Survey Data, 2016

For example, rainfall had positive correlation with maize (*Zea mays L.),* sorghum and millet at R^2=0.53, 0.39 and 0.48 respectively (See Figure 4.2). Consequently, the result in Table 4.4 indicates that the decrease in rainfall has been affecting the yields of maize, millet and sorghum at 90%, 65% and 45% respectively.

Further, the results from informative interviews, discussion and physical observations had similar findings. In the present study, the posed effects ranged from slight, moderate, severe and very severe. Maize and sorghum were the most and least vulnerable to rainfall variability respectively. Since, maize is a major cereal staple food crop to more than 70% of Tanzanian communities; its failure had repercussions to the whole country (URT 2014; 2013).

The studies by Challinor *et al*. (2014), Ahmed *et al*. (2011); Schelenker and Lobell (2010), Lobell *et al*. (2008) and Challinor *et al*. (2007), just to mention a few, had similar observation as they well found that, the yields for major staple cereal food crops like maize, sorghum and millet have been affected by climate impacts and will continue to be affected.

Table 4.4: Impacts of climate change (in percent) to a specific crop yields

Crop	Mnyakongo (n=200)	Ugogoni (n=200)
Maize	90 (very severe)	85(Very severe)
Millet	60 (Severe)	65(Severe)
Sorghum	50 (Moderate)	40(Slight)

Source: Field Data Survey, 2016

4.3.4.2 Temperature

The result in Figure 4.3 presents the impacts of temperature to crop production.

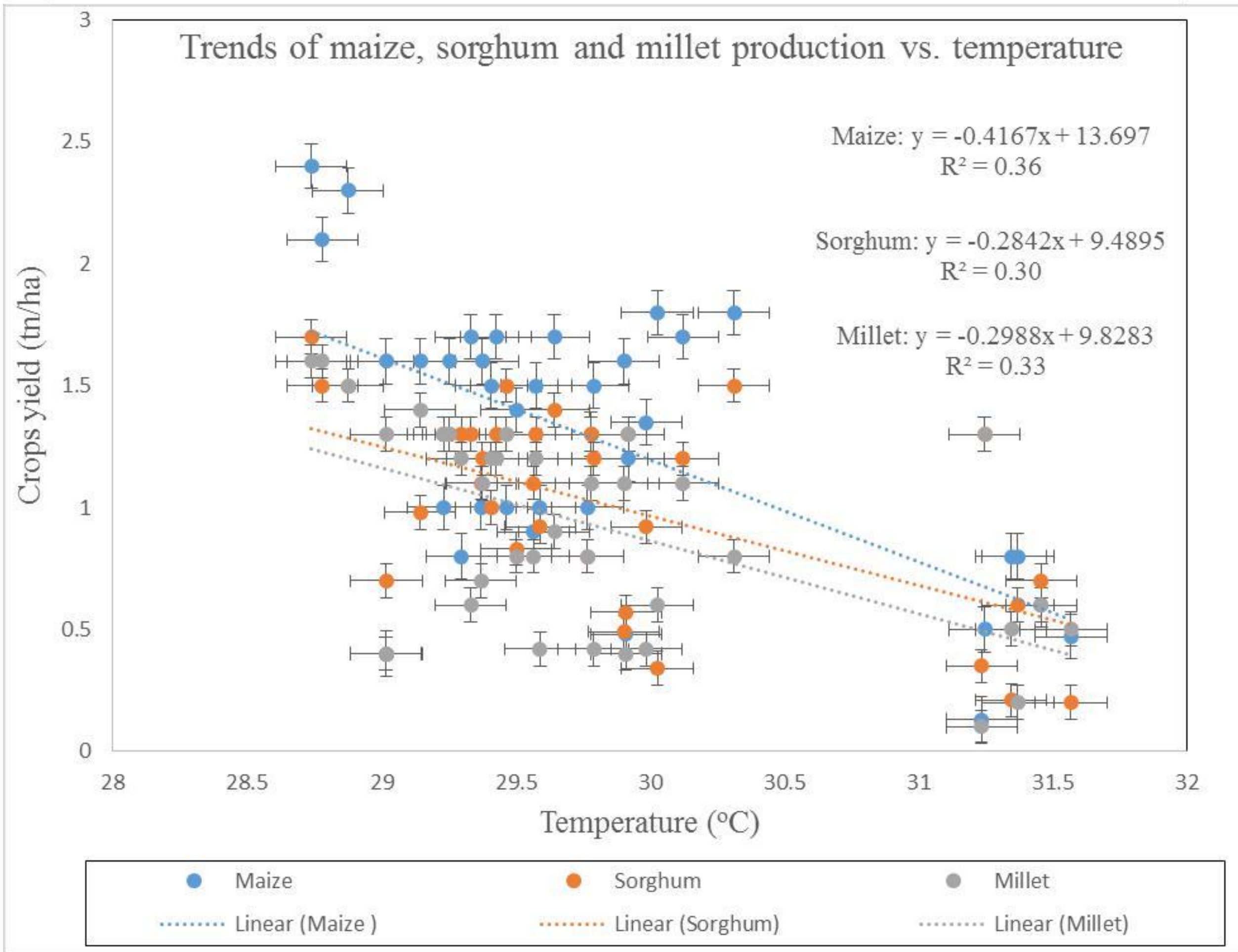

Figure 4.3: Correlation between temperature and crop yields in the study area

Source: Field Survey Data, 2016

Despite of temperature being a useful abiotic factor for crop production, however, its excess has negative impacts to crop productivity. Under this study, there were negative relationship between temperature alterations and crop yields in the area (*P* <0.05). Both Pearson's moment correlation coefficient and regression analysis showed that kind of correlation between these variables. In years encountered with high temperature, there were meagre yields and vice versa (Figure 4.3). For instance, temperature had negative correlation with maize (*Zea mays* L.), sorghum and millet at R^2=0.36, 0.30 and 0.33 respectively (See Figure 4.3).

However, maize and sorghum were the most and least vulnerable to temperature alterations respectively. Maize production was impacted by extreme temperature that resulted to meagre yields and eventually caused frequent food shortage to about 70% of the people. These results were also supported by the respondents in the study area

(Table 6). The findings from informative interviews, discussion and physical observations also supported the same. Besides, these results were in agreement with the studies by Mkonda (2011), Rowhani *et al*. (2011), Challinor *et al*. (2014) and Mkonda and He (2017b) which were conducted in diverse agro-ecological zones of Tanzania. Therefore, the direction of yield change in the study area depends on the state of current climatic condition, physiology of the crop and soil management of the area (Lobell *et al*., 2008; Challinor *et al*., 2014).

The rainfall projection from an assessment of 12 CMIP3 (AR4) GCMs over the Tanzanian context, suggested an increase in rainfall by the end of 21st century despite of the occurrences of extremes (droughts and floods). This will have substantial impacts to crop production through excessive droughts in most areas and floods in fewer lowland areas.

4.3.5 Impacts of Climate Change on the Ecosystems

Although most studies have focused on the direct impacts of climate change to the major livelihoods i.e. agriculture, these impact are further destructive to the ecosystems. The impacts of climate change especially droughts amplify the degradation of soil fertility and other soils microorganisms. The projected warming in east African countries can have significant impacts on the same. In terms of environment, the increase in temperature can affect the plant pathogens. In most cases, high temperature and excessive drought can affect microorganisms e.g. mycorrhiza. As well, high soil temperature can affect the seedling and crops (Figure 4.4).

Figure 4.4 illustrates the existing interrelationship among climate, agricultural production and ecosystems. The findings of this study are in agreement with other scholars like Paavola (2008) and Mwandosya *et al*. (1998) who proclaimed that the overall climate variability has impacts to agro-ecosystems. Mwandosya *et al*. (1998), further predicted that the expected increase in temperature by $2^{O}C$ and $4^{O}C$ by 2050 and 2100 respectively and will aggravate the situation. They warned that further exacerbation of the ecosystems will incapacitate the ecosystems to provide environmental services more especially soil fertility and water for both agricultural production and livelihoods.

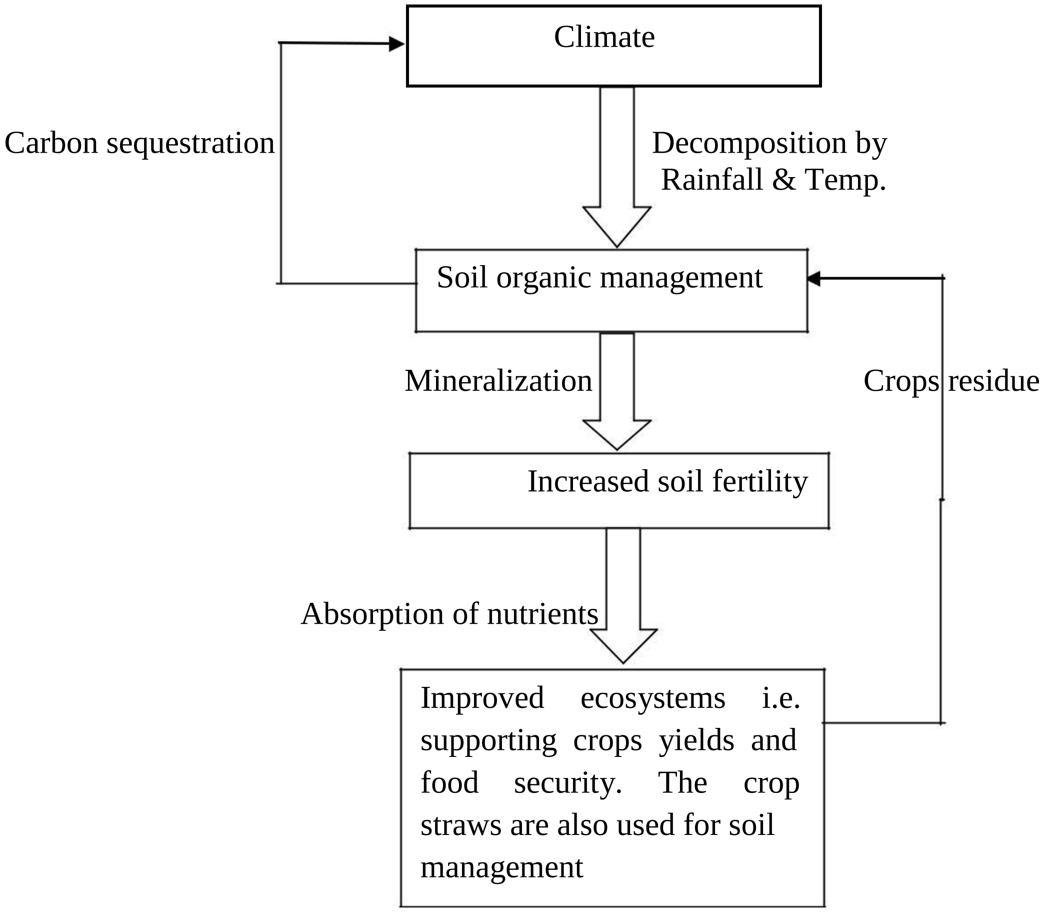

Figure 4.4: Relationship among climate, crops yields and ecosystems
Source: Mkonda and He, 2018b

4.3.6 Community Adaptation Strategies

The results in Table 4.5 indicate that early planting and small scale irrigation were the most (63%) and least (9%) adaptation measures in the area. In general, the farmers in the sampled villages (i.e. Mnyakongo and Ugogoni) have been applying both incremental and transformative adaptation strategies (Mkonda & He, 2017a). Incremental adaptation involves the improvement of the existing strategies such as the use of more drought resistant crops while transformative involves the complete change of strategies (Mkonda & He 2017b). Here farmers completely shift from agriculture to other economic activities such as business, employment, etc.

On the other hand, the timing of farm operation received high attention in both villages. An average of above 60% of the farmers went for it as they do so in November every year instead of December. This is done regardless of the availability of rains.

Moreover, about 50% of these farmers adopt resistant cultivars as a way of curbing the situation (i.e. climate impacts). For instance, they had adopted maize cultivars like TMV-1, Staha, Tan 250, Kilima and STUKA M1 which are drought resistant and can mature within 3-2 months. Further, about 45% and 40% of the farmers adopted fallowing and mulching respectively as their adaptation strategy.

Table 4.5: The existing adaptation and mitigation measures in the study area

Adaptation activities	Mnyakongo (n=200)	Ugogoni (n=200)	Average (n = 400)
Early planting	72%	54%	63.0%
Adopting resistant crop cultivars	55%	50%	52.5%
Mulching	35%	43%	39.0%
Agroforestry	23%	25%	24.0%
Crop rotation	35%	30%	32.5%
Small scale irrigation	10%	8%	9.0%
Fallowing	42%	48%	45.0%
Afforestation	20%	15%	17.5%
Transformative adaptation	21%	23%	22.0%
Conservation of water sources	25%	20%	22.5%

Source: Mkonda and He (2017a)

It was realized that there were very few irrigation scheme/rivers in the area (Figure 1.1 in Chapter One). For example, *Mseta River* had an irrigation scheme that at least serves the livelihood of few people who live around it. The farmers efficiently used water for irrigation under the auspices of Irrigators Organization (formerly water user association). These adaptation measures can be up-scaled or intensified to form adaptation plan that can be recognized/introduced in the policy. Although most of the adaptations are meant to improve agricultural production, they are also conserving the environment especially soil fertility (Hertel *et al.*, 2010). For example, organic fertilization can optimize yields and create favorable condition for microbial development and functioning.

4.4 Discussion

Although the study has used Tanzania as a case study, its findings are applicable in many countries of Sub-Saharan Africa where semi-arid and tropical climates are predominant (Hertel et al., 2010; Elliott et al., 2014; Serdeczny et al., 2017). This study has established the relationship among climate variability i.e. rainfall and temperature, crop yields and the environment (See Figures 2-5). The distinctions of rainfall and temperature variability have also been confirmed by this study. It has been revealed that the total annual rainfall and mean annual temperature were decreasing and increasing respectively (Figure 4.1).

This variation posed impacts to agricultural production (Tables 4.3 and 4.4) and environment (Figures 4.1-4.4). These results have complied with those established in different models at both local and global levels. For example, the projection of from an assessment of 12 CMIP3 (AR4) GCMs over the Tanzanian context, suggests the decrease in rainfall by the end of 21st century despite of the occurrences of extremes (droughts and floods). These models further reveal that the whole East African Region will experience more droughts incidences than flood.

In addition, the findings of the present study are in agreement with those by Mongi *et al.* (2010), Rowhani *et al*. (2011), Challinor *et al*. (2014), and Muller and Shackleton 2014) just to mention a few. In all means, these incidences have adverse impacts to agriculture and the ecosystems of the locality and thus, upsetting the sustainability of the peoples' livelihoods.

On the other hands, agriculture sector that employs over 70% of the people in Tanzania has been operating in diminishing return especially in the past 3 decades. This decline has been coupled by a number of factors but mostly being excessive droughts and increase in temperature (Hertel *et al*., 2010). For example, the yields of maize, sorghum and crops from (1980-2015) in tons per hectare fluctuated significantly (Table 4.3). The impacts of climate change that involve prolonged number of dry days also have had adverse effects to this agricultural turbulence. The optimal shift of rains onset and sensations, and reduced the number of wet days and the shrinking of the growing season have affected the farming calendar in the area. Previously, rain onset occurred in December while cessation was in April. Thus it was understandable on when farmers could start their farm operation.

Similarly, various models showed that an increase of 2^{O}C in temperature during the growing seasons (1992 -2005) reduced maize and sorghum yields by 18.6±5.2% and 12.6±5.3% respectively while an increase of 20 mm in average monthly precipitation during that time increased yields by 6.7±1.7% and 5.7±1.7% respectively (Rowhani *et al*., 2011). Similarly, Figure 4.1b showed that the increase in temperature influenced the decline of crop yields. The scenario of increased temperature mostly impacted maize than millet and sorghum respectively (Figure 4.3).

It was also evident that maize i.e. a major staple food in the country had high sensitivity to temperature above 30^{o}C (Luo 2011). Lobell *et al*. (2011) coincided that each day of the growing season with such amount of temperature reduces yields by 1% compared to optimal, drought free and rain-fed conditions. In this aspect, maize was the most vulnerable to rainfall variability while sorghum was the least vulnerable.

Since maize is the most preferred food to over 70% Tanzanians, its yield decline has significant repercussion to the majority livelihoods (URT 2014). In years with worst yields, the farmers become more vulnerable, destitute and sorrowful. Despite the fact that the area has already been experiencing temperature above the optional range, it is projected to increase in future (Mwandosya *et al*., 1998). Therefore, compelling adaptation measures need to be adopted to curb the vain and elevate the living standards.

Temperature alterations further increased evapotranspiration and thus, affecting crops production and increasing farmers' vulnerability. This observation is in agreement with the study by Rowhani *et al*. (2011) who argued that, the adaptive capacity of vulnerable smallholder farmers is significantly weakened by increased stress due to climate change impacts. On the other hand, Sen (1986) devised that vulnerability increases among the poor people due to lack of resource endowments and entitlement failure. By comparing the wealthy and destitute, the author found that the former had compelling resilience than the latter. Respectively, most smallholder farmers in the Tanzania's semi-arid agro-ecological zone are destitute and thus are easily affected by any challenging conditions posed by any environmental stress (Mkonda and He 2018b).

Despite plotting the total annual rainfall and temperature, the intra-rainfall variability had significant impacts to crop production during the growing seasons. In the area, January is a planting month but has been experiencing high rainfall variability in terms of intensity, frequency and amount. This variation has implications on the production process of the crops. In years when the month received optimal rains, the yields were significant high and vice versa (Mkonda and He 2017a). For example, in

1985, 1990, 2002, 2008 and 2014 there were a bit high total annual rainfall and crop yields (Figure 4.1 and 4.2). In contrast, 1988, 1995, 2005 and 2014 there were low total monthly rainfall and little yields. Thus, in years with low rainfall, the vulnerability among the smallholder farmers increased significantly.

In most scenarios, February was the driest month in the growing season compared to January and March (Mkonda and He 2017a). This was evidenced by the result from meteorological analyses and responses from farmers in the study area. The month experienced low total rainfall and wet spells (see Figure 4.1a). Besides, about 80% of the farmers supported that, February had low rains and fewest wet spells. However, better yields were also reported when February had optimal amount of rainfall and a number of wet days. For example, in the years 1982, 1990, 2005 and 2012 there were high rainfall and crop yields while in 1985, 1988, 2001 and 2010 as seen in Figure 4.1a&b. Low yields elevated food shortage and further vulnerability to the destitute farmers. March had optimal rains in terms of both total and wet spells. During March, most crops were always at ripeness stage and thus, the month (March) greatly determines crop yields.

In addition, the farmers asserted that, in successful years, during March; the drought resistant and early maturing maize varieties i.e. Staha, TMV-1, STUKA M1, Kilima-ST and Tan 250, and sorghum varieties i.e. *Macia* are almost at completed stage of ripeness. These breeds are early maturing, gives high yields and tolerant to drought and nitrogen deficiency. However, the general trend showed that for the past 36 years, March has experienced climatic turbulence and thus, not giving the best in terms of both the frequency and intensity of rains. By doing so, it has significantly affected crop yields (P <0.05). Fortunately, in some few years when it was at its best, there were optimal yields. Just to give few incidences, in 1981, 1988, 1993 and 2012 the month had high total rainfall and numerous wet days, and concurrently increased in maize, sorghum and millet yields (Figure 4.2). This is contrary to 1985, 1990, 2000, 2010 and 2014 just to mention a few, when both rains and yields were low (4.2).

Recently, in 2015 the level of household self-sufficient ratio in the area was around 70% and thus making the magnitude of food insecurity in the area to be around

30% (URT 2005; 2007; Mkonda and He 2017b). In some areas, this deficit accrued to 50% depending on the level of livelihoods vulnerability.

This percent (50%) implies that if livelihood options are not well established, the situation could lead into serious problems i.e. hunger, famine, diseases and death just to mention a few. Since frequent food shortages have been reoccurring for the last three decades, this justifies that no compelling measures have been taken to fully address the disturbing crisis. This study calls for a compelling mechanisms to optimize crop yields aimed at curbing the mentioned challenges.

Likewise, various studies have also been established on the impacts of climate change on livestock production (URT 2007). Thornton *et al*. (2011) confirmed that despite livestock being a source of income, or insurance in many countries (especially Tanzania), its production has been significantly affected by climate change. This happens because most pastoral systems of the arid and semi-arid lands of Tanzania and other Sub-Saharan countries are highly dependent on the limited natural resources, more especially pasture, fodder, forest products and water (Mkonda and He 2018c).

These resources are limited because they are also directly affected by climate variability (Morton, 2012). In the study area and other parts of central and northern Tanzania especially Singida, Dodoma, Arusha and Manyara regions just to mention a few, there has been increased incidences of animal deaths due to excessive droughts. In all means, this has increased the level of vulnerability and poverty among the people.

Moreover, climate change has negatively affected diverse ecosystems of the area and thus affecting the provision of environmental services (Luo, 2011). Among other things, the major entities of the ecosystems include but not limited to soils, water, vegetation, microorganisms and animals. In a wider perspective, the development of good ecosystems needs to have a balanced mutual relationship among the members of a particular ecosystem. Many of the areas that are classified as semi-arid areas in Tanzania are adversely affected by prolonged droughts thus far, most of the important aspects of various ecosystems are not well functioning (Serdeczny *et al*., 2017).

It also appeared that most water sources have dried out due to drought. Various vegetation species such as *miombo woodlands* have almost disappeared leaving the *cactus* because they are drought resistant. As results, most of the carbons that were stored in the plant biomass before degradation off set in the atmosphere (Zomer *et al.*, 2008); this is also depicted in Figure 4.4 of this study. As a way of curbing this, soil organic management can be recommended to optimize the functions of microbial activity and soil mineralization. This can optimize the formation of organics matter, soil fertility and soil carbon accumulation.

Soil organic management i.e. conservation agriculture, irrigation and good agricultural practices just to mention a few, are significant factors for crop production as they form a complex web of agricultural systems. However, under rain fed agriculture, improved soil management alone may not bring the expected crop yields, but the combination of diverse farming approaches can do it. This is because climate change impacts also affect water sources, forestry and a wide of biotic ecosystems in diverse locations. In most cases it has been discerned that the affected ecosystems i.e. dried water sources cannot further serve the livelihoods of the people (Kangalawe 2016).

To underpin the climate resilience, there is a need to improve the existing adaptation and mitigation measures (Table 4.5). Among others, include; good agronomic practices, organic fertilizations, conservation agriculture, small scale irrigation and adoption of drought tolerant breeds. This will optimize the yields, carbon sequestration and environmental conservation which all are important for sustaining peoples' livelihoods. Therefore, this study has confirmed that the variability of the intensity, onset and cessation of rains has posed significant negative impacts to both agriculture and livelihoods at large. To reduce the vulnerability of climate change impacts; all stakeholders have to play their role at their best level, and for smallholder farmers to get the expected yields, they should adhere to proper adaptation strategies which are relevant to their locality.

4.5 Conclusion

Although it is evident that climate is changing, it's realistic especially on the magnitude of change and impacts to agriculture and ecosystems is not yet well established across the whole country. This study found that, there was a temporal climate change and variability in the study area (semi-arid agro-ecological zone). This was evidenced by the results from both meteorological and farmers' perceptions analyses.

Further, these results confirmed that local communities especially old people had significant awareness on the same. At local level, rainfall variability had been the major concern to the farmers and other climate practitioners. In this respect, rainfall varied in terms of amount, occurrences and intensity. On other hand, there was significant relationship between climate variability and crop yields (P <0.05). This was confirmed in the study area as the increase in rainfall influenced optimal yields and vice versa. However, this was contrary to temperature that increased with the decrease in crop yields and vice versa.

Despite the maize being the preferred crop, it was the most vulnerable to climate alterations compared to sorghum and millet (Figures 4.2 and 4.3). Thus, the decline of maize yields had significant repercussion to the status of food security in the area and at national level. In addition, the diminishing yields increased land conflict, poverty and degradation. These happened as people were seeking for optional livelihoods. Thus, the changing climate affected the entire livelihood of the destitute communities which entirely depend on rain fed agriculture.

To curb the problem, a robust policy and sound tools associated with raising climate resilience need to be in place. Further, a set of compelling adaptation plans and measures need to be adopted by farmers corresponding to the biophysical characteristics to optimize crop yields to curb frequent food shortage.

Chapter Five: Conservation Agriculture for Environmental Sustainability in Tanzania's Semi-arid Agro-ecological Zone under Climate Change Scenarios

5.1 Background Information

5.1.1 Introduction

The significance of soil or environmental conservation to limit soil degradation has been advocated since 1903 (Jenrich, 2011). The current situation of a rapid population increase and global climate change has necessitated the practicability of such soil conservation (Vanlauwe *et al.*, 2014). For example, the USA government has invested millions of US dollars yearly to support conservation related projects (Baker *et al.,* 2007; Lal 2012). To increase fruit production and environmental conservation the organic farming in Australian vineyards, where both mulching and composite, is mostly used as conservation agricultural practices (Penfold et al., 2003). This practice increases crop yields and environmental conservation in various areas of the country.

The increasing extreme of weather changes especially for temperature and precipitation has significantly impacted the nutrient cycling and soil moisture in most Sub-Saharan Africa (Thierfelder *et al.*, 2012; Ngwira, *et al.*, 2014). Seemingly, these weather changes can intensify in the future because various climate models are predicting further climate alterations. In doing so, the production systems are expected to worsen and this problem will be intensified by high outbreak of diseases, pests and pathogens which will also affects crop production.

To intervene these authentic and potential consequences we need to develop resilient agricultural systems through rational and affordable strategies that maintain the ecosystem functions and protect the livelihoods (Mattee 1994; Rogers *et al.*, 1995; Mwaseba *et al*, 2006). Various studies have recommended different CA practices to adapt and mitigate climate impacts (Delgado *et al.*, 2012). Literally, CA features in various forms such as organic soil management, agroforestry, and crop rotation just to mention a few. Bennett *et al*. (2011) and Malviya *et al*. (2013) in their model found that legumes are potential for both crop yields optimization and environmental services.

Moreover, Zhu *et al*. (2017) realized that organic matter from dead debris and litter decomposition are of great important in improving soil fertility in various ecosystems. These organic soil management systems are important aspects of CA.

Since smallholder farmers are vulnerable to extreme change of rainfall pattern, CA can be their best preposition to elevate their resilience (Paavola, 2008; Challinor *et al*., 2014). This is particularly important because it is expected that by the year 2030 Africa will have 120-150 million smallholder farmers and most of them will rely on rain-fed agriculture for their subsistence (FAO, 2008). While the dependence on rain-fed agriculture expects to increase, the projections from an assessment of 12 CMIP3 (AR4) GCMs over Africa suggest an extreme variation in rainfall by the end of the 21st Century (IPCC 2014). In that respect, the susceptibility of the farmers will further increase due to such increased challenging condition (Nyong *et al*., 2007; Neufeldt *et al*., 2013).

Specifically, the farmers' vulnerability is expected to be worst in dry areas (arid and semi-arid) due to increased effects to the already stressed areas (Nyong *et al*., 2007; Neufeldt *et al*, 2013; IPCC 2014; Duru *et al*., 2015). The impacts in these areas cannot be underestimated because the global dry land areas cover about 41% of Earth's surface and sustain the livelihoods of about two billion people (Duru *et al*., 2015; Plaza-Bonilla *et al*., 2015). In these areas, drought is exacerbated by the global increase in temperature and extreme decrease in rainfall (Ye *et al*., 2013). Similarly, many studies have revealed the increase of global surface temperature for 0.8^{O}C during the past century and mostly in the last three decades (Rowhani *et al*., 2011). This has also increased the deterioration of the agricultural systems. Subsequently, this deterioration has exerted more pressure to the already stressed environmental resources through overutilization and thus, posing more complexity in its management when needing to restore (Ahmed *et al*., 2011; Rowhani *et al*., 2011; Ye *et al*., 2013; Plaza-Bonilla *et al*., 2015).

Kimaro at al. (2015) cautioned that despite of the excessive droughts in most dryland areas, there has been significant degradation of soil fertility. This soil fertility degradation is mostly accrued by poor agronomic practices and excessive artificial chemical fertilization (Vanlauwe, 2004). To curb the situation, Vanlauwe *et al*. (2014) proposed CA to elevate soil fertility and mitigate climate change impacts. Their study explicitly explained that, CA can operate in different forms and principles such as terraces or ridges, minimum tillage cropping, cover cropping, large pits and intercropping especially legume intercropping of sweet beans and lablab. Similarly, Neufeldt *et al*. (2013) asserted that CA has increased soil fertility, crop production and carbon sequestration in most areas where has been effectively applied. Other scholars such as Hartemink *et al*. (2008) and Haoa *et al*. (2016) further mentioned that CA is a possible mechanism for climate change adaptation and mitigation.

Under CA, soil microbial communities become responsible for a wide range of soil functions and ecological services such as organic matter turnover and nutrient cycling (nitrogen, phosphorus and carbon) just to mention a few (Lienhard, *et al*., 2013; Duru *et al*., 2015). These authors advocated CA because it is economically viable and environmentally friendly. Recently, CA has been proposed in most African countries to be used as Climate-Smart Agriculture (CSA) (Neufeldt *et al*. 2013; Harvey 2014). According to FAO (2013), CSA is about land management practices that elevate food security, resilience or/and adaptive capacity of farmers to climate variability impacts and also mitigate climate change by seizing carbon in biomass and soils, and/or reducing emissions when possible.

Similarly, Lal (2015) promoted little tillage as a powerful tool of retaining soil carbon and improving soil fertility by integrated soil nutrient management for healthy crop growth and biochemical transformation of biomass carbon into the soil organic matter or humus. This was supported by Mohammadshirazi *et al*. (2016) who realized that conventional tillage losses soil nutrients and water through infiltration. The studies by Hartemink (1997) and Glaser *et al*. (2001) conducted in eastern Tanzania and northern respectively further informed that little disturbance of the soil has significant ecological potentials. However, despite this significance, there has been high inconsistence of CA adoption in most Sub-Saharan Africa where about 70% of agriculture industry is under smallholder farmers (i.e. who are most vulnerable to global climate changes). Their vulnerability is accrued by the high dependence on rain fed agriculture, and entitlement failure (Sen, 1999). Thus, despite the significance of CA, the adoption rate has not been sufficient in most Sub-Sahara Africa (Figure 5.1).

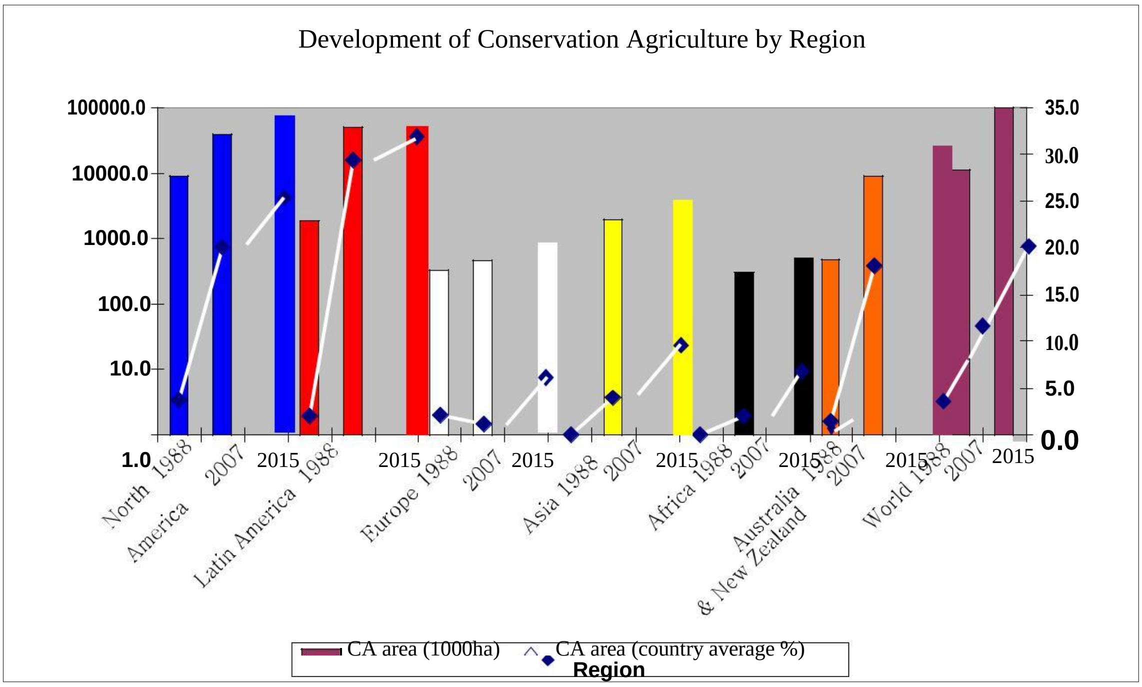

Figure 5.1: Development of conservation agriculture over the last 20years by world region in total area (ha) and as an average percentage across the adopting countries of the respective region. In this figure; the left Y axis shows the total area (ha) while the right Y axis shows the average percentage (%). African countries seem to adopt conservation agriculture slowly. It needs more emphasis for a good take off. Afterwards, the continent will increase crop yields in terms of quantity and quality as well as conserving the ecosystems.

Source: Modified from Mkonda and He, 2017c.

Most sub-Saharan African countries had recently started the adoption of CA. For example, Malawi, Zambia and Zimbabwe intensified their CA adoption in 1990s (Glaser *et al*., 2001; Thierfelder *et al*., 2012; Ngwira *et al*., 2014). Having been informed on the significance of CA, there is an immediate need to emphasize the optimal adoption and utilization of CA in the region (sub-Sahara Africa) where most farmers are destitute and marginalized.

5.1.2 Overview of Conservation Agriculture in Tanzania

Most Tanzanian communities adopted indigenous agricultural conservation techniques e.g. *the matengo pits* (terraces) in Ruvuma, *Chagga garden* (agroforestry) in

Kilimanjaro and *ngitiri* (enclosed pasture) in Shinyanga regions to intervene the challenges associated with environmental stress. They did so to optimize crop yields, increase fodder, control erosion and conserve moisture and fertility in the soil (Sosovele *et al*., 1999). Despite of that, CA is trivially practiced in the country and it has been operational in few regions such as Dodoma, Manyara and Arusha (Kahimba *et al*., 2014). CA receives little attention from the Tanzania Agricultural Policy 2013) as the existing policy advocates the green revolution that emphasizes more on conventional tillage and chemical fertilization. The few CA practices practiced in the aforementioned regions involve agroforestry, crop cover and crop rotation and are mostly influenced by donors (Vanlauwe 2004; FAO 2006; 2012). Thus, policy setting has greatly affected the CA adoption in the country.

At household level, the adoption of CA or any other agricultural technology is reached after the adopter has satisfied before that decision. In most cases, the household adopt new agricultural technology (i.e. AC) whose net benefits are significantly greater than that of the existing/dropping technology. In this approach, the prospective and new technology adopters observe the utility gained by the early adopters before adopting that technology. This can be described in various models.

For example, the Heckman model (1979) specified the decision and extent of technology adoption as follows:

$$Ci = Zi\varphi + \varepsilon i \text{ (CA adoption)} \quad \text{(a)}$$

$$Yi = Xi\beta + \mu i \text{ (extent of CA adoption)} \quad \text{(b)}$$

Where:

Ci is a dummy variable for CA adoption,

Zi is a vector of determinants of CA adoption,

Yi is the extent of CA adoption (proportion of land area under CA),

Xi is a vector of determinants of CA extent of adoption,

θ and β are vectors of parameters to be estimated, and εi and μi are error terms.

Basing on the Heckman model (1979) for the estimated parameters of equation b to be efficient there should be no correlation between the two error terms (εi and μi). Nevertheless, the sample selection bias, results in a non-zero correlation between the two errors. To correct for this selection bias, the Heckman, the model first estimates the first stage (a) to obtain a sample selection indicator called Inverse Mills Ratio (IMR). This is suitable in measuring the covariance between the two errors. The study by Rogers (1995) had agreement with Heckman model as it informed that 'the innovation-decision process can lead to either adoption, a decision to make full use of an innovation as the best course of action available, or rejection, a decision not to adopt an innovation'. Few studies have been conducted to assess and evaluate the extent of CA in the country. The study by Kimaro *et al*. (2015) which is among the famous CA studies conducted in the country was conducted in Uluguru Mountains (Eastern Arc Mountains) and focused on maize yields.

However, the present study focused on semi-arid agro-ecological zone and earmarked on maize, sorghum and millet. This study focused on semi-arid because the areas are the most vulnerable to climate change impacts and environmental degradation. In these areas, CA is the surest way of limiting these two major challenges. The dominant farming systems in most semi-arid regions includes: cropping, pastoralism and agro-pastoralism i.e. integration of crops with livestock (Sosovele, 1999). This integration increases biomass inputs in the soil systems, incorporation of perennial plants in farming systems and optimization of nutrient amendments in the soil (Linhard *et al*., 2013). This web system also increases the mutual interactions between plants roots and mycorrhizae fungi and eventually elevate nutrients uptake and resistant to pathogens by plants.

Although the science of CA and its significance at global level is progressing rapidly, a variety of knowledge gaps still exist especially in developing countries. This research was geared to assess the rate of CA adoption and assess its ecological significance in semi-arid areas of Central Tanzania. Despite of some FAO-CA projects that have been conducted in some Tanzanian regions hitherto, their impacts have remained trivial (FAO 2006; 2012).

This study was hypothesized as follows:

H1: The rate of CA adoption is influenced by the desire of farmers to have optimal yields, preservation of soil moisture and fertility, control of soils erosion, and reduction of labor work.

H0: The rate of CA adoption is not influenced by the desire of farmers to have optimal yields, preservation of soil moisture and fertility, control of soils erosion, and reduction of labor work.

The above mentioned items in the hypothesis were widely known to the respondents and thus, it was not difficult to differentiate or/and synthesize one another during data collection and interpretation.

The level of CA adoption in the semi-arid agro-ecological zone of central Tanzania was investigated. It was quite important to conduct such a study because most semi-arid areas experience frequent food shortage associated with degradation and extreme climate change impacts. Thus, the present study explored the rate of CA adoption and is socio-ecological significant to the community and environment. To achieve this objective, the rate of CA adoption was hypothesized against the factors for its adoption.

The findings of such a study are expected to have significant contribution to the establishment of CA promotion policies in the country with an earmark to the vulnerable communities and ecosystems. The policy advocacy on CA is a significant move toward sustainable adoption of CA in all country’s agro-ecological zones.

Recently, the adoption of CA is determined by personal characteristics (i.e. knowledge and experience), physical factor (land availability), social and financial factors. Despite of insignificant willingness in CA adoption, the practice has numerous fruitful results as it improves biological functions of the soil through mycorrhizae fungi, aunts and worms that elevates nutrients uptake by the plants.

5.2 Materials and Methods

5.2.1 Conceptual Framework

The basis of the study findings was field work with a constructed conceptual framework (Figure 5.2) enlisting the salient CA aspects. The framework portrays the major roles of conservation agriculture; first as a tool for increasing crop yields and secondly as a tool for environmental conservation. CA improves the fertility of the soil through no or reduced tillage, mulching, agroforestry and crop rotation (Major CA in the study area). It increases crop yields in terms of quality and quantity. By so doing, it limits food insecurity and abject poverty. It further preserves the biodiversity and it mitigates the emission of greenhouse gases (GHG's) i.e. CO_2, CH_4 and N_2O.

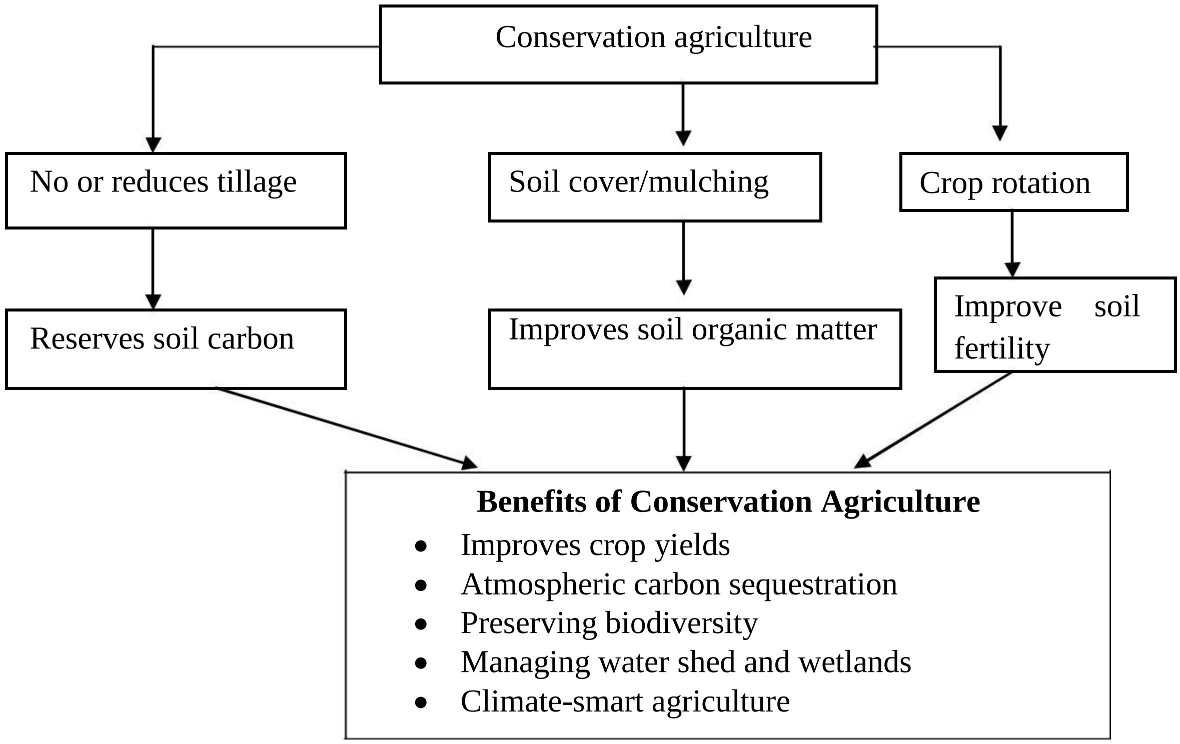

Figure 5.2: Conceptual framework for conservation agriculture
Source: Mkonda and He, 2017c

5.2.2 Agricultural Systems in the Area

With a 3637 km2 of arable land, the study area is dominated by cropping systems, pastoral systems and mixed farming. About 80% of the cropping systems are under smallholder farmers whose main farming tool is hand hoe (Sosovele *et al.*, 1999). The medium scale farming (about 17%) uses power tillers while large scale (about 3%) uses tractors in their farming activities.

The dominant food and cash crops produced in the area includes: maize, sorghum, millet, common beans, cassava, sweet potatoes, chick peas, sesame, cashewnuts, sunflower and groundnuts while the dominant animals kept in the area are cattle, sheep, pigs, donkey and goats. In the area, there is one ranch owned by National Ranching Company and one pasture Research Center.

5.2.3 Methodology

Simple random sampling was employed in selecting the study area. We picked one district was picked among numerous that are severely impacted by climate change and experience frequent food shortage. Purposive sampling was employed in selecting representative villages i.e. Mnyakongo and Ugogoni. Priority was given to villages practicing CA. Reconnaissance survey was done in April 2016, two months before the actual data collection process. During this phase, data collection tools were tested to determine their effectiveness. Also this phase was used to process the required research permits and determine some key informants. All discrepancies raised during this phase were fixed before the actual process of data collection.

The actual data collection process was embarked from June to September 2016. Household surveys, group discussions, informative interviews and physical observation were employed for data collection. These tools were simple and suitable because they optimally involved relevant stockholders. Simple random sampling was applied when selecting households while systematic sampling was used to form groups for discussions.

In addition, purposive sampling was employed in selecting the interviewees. Intensive interviews were conducted with agricultural experts, extension officers and few elders. The data on CA (i.e. acreage under CA) and crops yield were gathered from Kongwa District Agricultural and Livestock Development Officer (DALDO) and Ministry of Agriculture, Livestock and Fishery. The acreage data about areas under irrigation were gathered from Dodoma Region Zonal Irrigation Office (in which Kongwa is affiliated).

A total of 400 questionnaires were collected from household heads of smallholders (farmer/livestock households). The questionnaires involved both closed and open questions. The selection of households was done by dividing the total number of the households in each village by the required sample size (about 10%). The household lists were obtained from village government leaders in the study area.

Interviews and household survey were used to collect socio-ecological data at society level. Both quantitative and qualitative data at field and farm level were collected. About 258,219 ha (71%) of the total arable land (363,690 ha) in the district was cultivated by 45,271 households. The two representative villages had 4500 farming households with about 16000 ha. Since the study aimed to explore the rate of CA adoption, 400 households (farmers) were selected from the two villages on a random basis (Table 1.4 in Chapter One).

Holistically, these 400 households had a total of 1600 ha (an average of 2-4ha) under crop production. The overall farmers' perception on CA was determined and its types and befits. In the process, we also determined the availability of extension services and the existence of farmer field school. Finally, information on soil characteristics were obtained from the Kongwa District Land Use and Planning office and some were extracted from literature review.

Participatory Rural Appraisal method (PRA) was also employed to collect socio-economic data at field level. These PRAs include informative interviews, group discussion, and physical observation just to mention a few. The application of the PRA method has been used in various studies to explore perceptions of rural communities on environmental issues that affect their lives (Cramb *et al*., 2004; Brown 2006; Humphrey and Kimberly 2007). At least a single group discussion comprising 15 people was convened in each village, and 20 interviews with agricultural experts, farmers, livestock keepers and village government leaders (See Table 1.4 in Chapter One).

5.2.4 Data Analyses

The quantitative data were analyzed using the Mann-Kendall Test (at 95% level of confidence), and Microsoft excel (window 13) software. The qualitative data from the household surveys were analyzed using theme content methods whereas, the qualitative information were summarized and inserted in the text during discussion. Tables and graphs were the appropriate methods for data presentation.

5.3 Results

5.3.1 Adoption of Conservation Agriculture

The findings showed that, despite the recently increased rate of CA adoption (Figures 5.3, 5.4 & 5.5, and Table 5.1, 5.2 & 5.3), very few (<10%) households had adopted it. In the two representative villages, 400 households cultivated an area of about 1600 hectares for crop production; however, about 10% of these households were practicing CA in 200 hectares. At district level, there were 45,271 farming households which cultivated 258, 219 hectares (Table 5.1). However, it was revealed that few households (4300) had adopted CA in 20000 hectares.

The result from Table 5.1 further indicates that Ugogoni Village had optimally adopted CA practices than Mnyakongo Village. The former had higher average land size, average land under CA, total cultivated land and the estimated land under CA than the latter. Empirically, this difference brought significant differences in terms of socio-ecological benefits to both the community livelihoods and the environment.

Table 5.1: Current and estimated land under conservation agriculture in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania

Village	Total cultivated land (ha)	Average-landholding size (ha)	Average land under CA (ha)	Adoption rate (%)	Estimated land under CA (ha)
Mnyakongo	8,600	3.5	0.34	8.7	90
Ugogoni	9,200	4.1	0.38	11.4	105

Source: The adoption rate was from the agricultural officers and others from local farmers in a 2016 field survey obtained from agricultural officers and the farmers.

In addition, Table 5.1 above indicates the collective types and forms of CA in the area whether are agroforestry, mulching, crop rotation or minimum tillage. It shows that there were correlation between the lands allocated to CA with the total land under farming (P <0.05). Hence, predictions and extrapolations can be done basing on such a dimension.

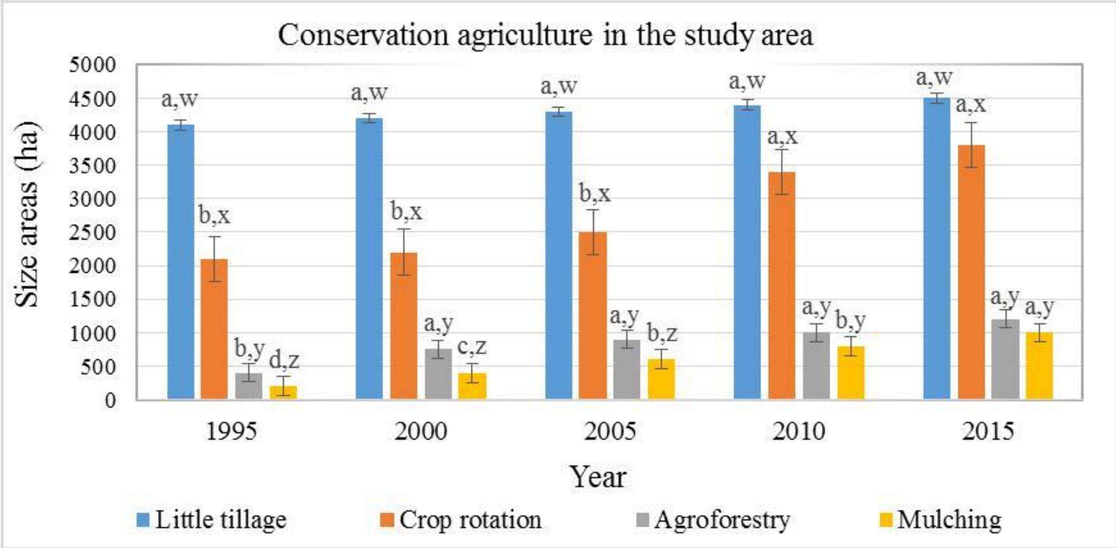

Figure 5.3: Variation in land use or farming systems from 1995 to 2015 (5-years averaged data) in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania. Data (means ± SD, n=5) follow different letters denote significant differences between averaged years for the same CA practice (a, b, c, d, e) and between different CA practices for the same averaged year (w, x, y, z) at $P < 0.05$. Note: Little tillage involves shallow cultivation (minimum tillage) of the farm (i.e. non-conventional

Source: Field Survey Data, 2016.

Figure 5.3 indicates the temporal trend of CA adoption with special focus on little tillage, crop rotation, agroforestry and mulching. There has been slight increase in about all CA practices though little tillage and crop rotation has been highly adopted compared to others.

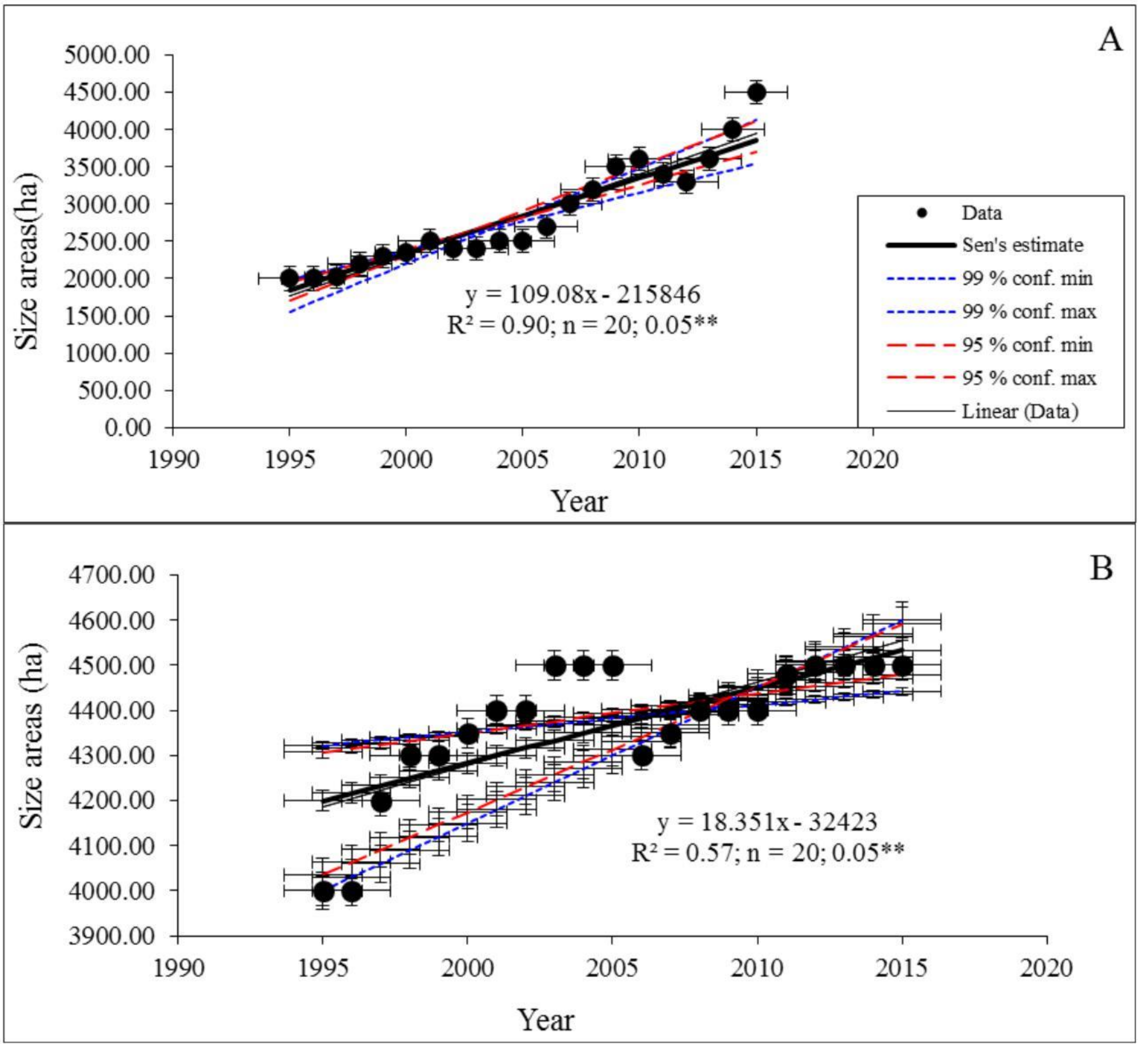

Figure 5.4: Adoption rate of crop rotation (A) and little tillage (B) as CA practices in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania.

Source: Field Survey Data, 2016

Figure 5.4 above shows the adoption disparities between crop rotation and little tillage. In terms of acreage, little tillage had more land (5000 ha) under practice than crop rotation (4500 ha). Meanwhile, crop rotation was significantly adopted (R^2=0.90) than little tillage (R^2=0.57).

Under such premises, it was evident that little tillage had fewer new adopters than crop rotation probably because it had already adopted even by the laggards. These results are in agreement with those by Kimaro *et al*. (2015) who also found that little tillage as a leading CA in Tanzania despite of somehow being integrated with mulch, crop cover and legumes.

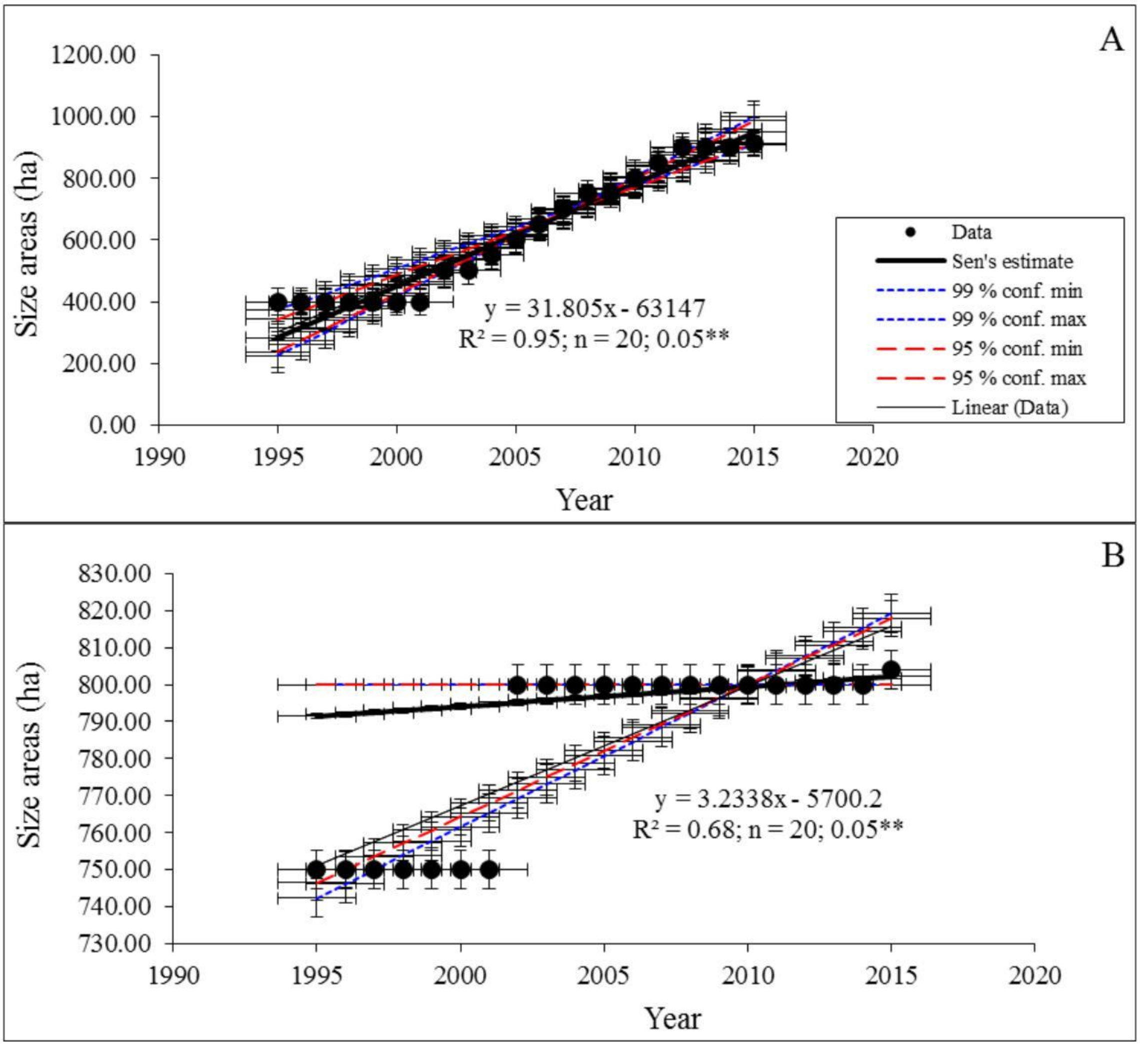

Figure 5.5: Adoption rate of mulching (A) and agroforestry (B) as CA practices in the study area. **Source:** Field Survey Data, 2016

Besides, mulching and agroforestry (Figure 5.5) appeared to have small area under acreage (1000 ha) as seen in Figure 5.5 but they had high rate of adoption. Of these two, mulching appeared to have higher adoption rate (R^2=0.95) than agroforestry (R^2=0.68) and it was evident the former received more new adopters.

This is because much of the adoption was done within the past 20 years (1995-2015). Since CA adoption is not much promising, there is an immediate need to establish compelling efforts that can make CA understandable and sustainable to farmers (Table 5.2). In this era of global climate change, CA can significantly increase the resilience of the farmers. Therefore, intensive adoption of CA will optimize sustainable livelihoods especially to vulnerable and deprived smallholders.

Table 5.2: Responses (%) of effectiveness to the conservation agriculture practices by local farmers (n = 200 in each village) during a 2016 field survey in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania

Conservation	Very effective		Moderate effective		Not sure		Not effective	
methods	Mn	Ug	Mn	Ug	Mn	Ug	Mn	Ug
Agroforestry	18	19	76	77	0	0	6	4
Crop rotation	71	73	22	25	7	2	0	0
Little tillage	15	16	67	71	13	10	5	3
Mulching	27	29	62	64	9	5	3	2

Abbreviations: Mn, Mnyakongo, and Ug, Ugogoni

Source: Field Survey Data, 2016

The result in Table 5.2 indicates most farmers (50-70%) asserted that the effectiveness of CA has been either very high or moderate. Most of them (71%) asserted that crop rotation (i.e. among the dominant crops e.g. maize, sorghum, millet, groundnuts etc.) has been very effective while very few (7%) were not sure if the practice was effective or not. Likewise, most farmers (76%) asserted that the effectiveness of agroforestry has been moderate throughout though 6% said it was not effective.

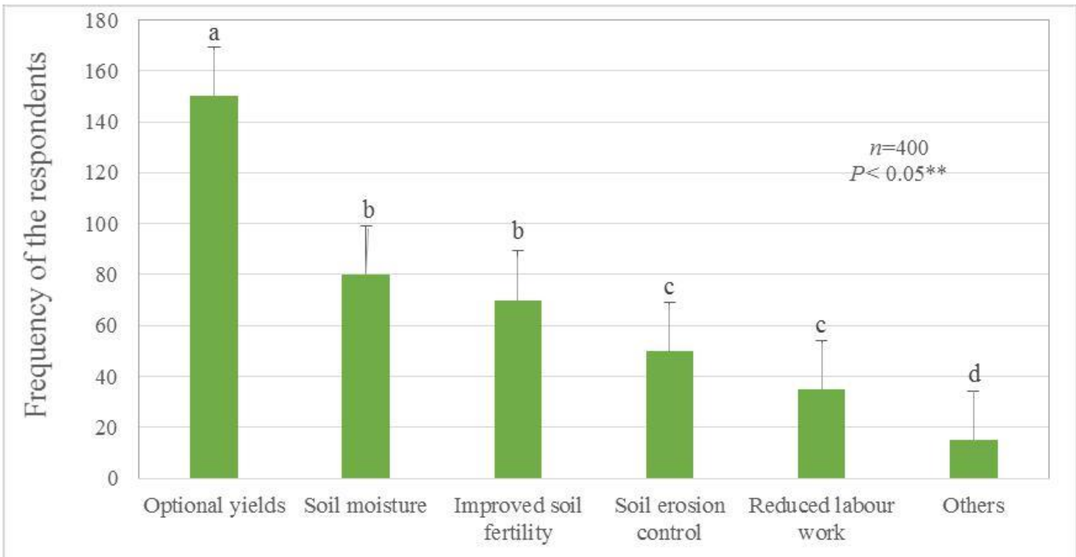

Figure 5.6: Reasons for adopting CA in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania. Different statistical letters (a, b, c, d) denote differences between different reasons for CA adoption. **Source:** Field Survey Data, 2016

Figure 5.6 indicates that most farmers essentially adopted CA practices to optimize yields. This notion was also observed in various studies and models (Heckman 1979; Rogers 1995 and Mwaseba *et al.*, 2006). Literally, improvement of agro-ecosystems such as soil moisture fertility retention, and control of soil erosion were other substantial reasons for CA adoption in the area

Table 5.3: Established hypotheses as expressed in % (From participatory research appraisals)

Village	Optional yields	Soil moisture	Soil fertility	Erosion control	Reduced labor	Others	Total
Mnyakongo	21	7	8	8	5	2	49
Ugogoni	19	8	8	7	5	2	51
	40	15	16	15	10	4	100

Source: Data are from a 2016 field survey in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania.

Figure 5.6 above represents the farmers assertion based questionnaires survey while Table 5.3 presented the findings from PRAs (i.e. mostly from discussion and interviews), though the results from these two sources correlate.

5.3.2 Crop Yields

CA has proved to have significant contribution to crop yields. In the present study, there were significant difference (P <0.05) between the yields from farms under CA and without (Figure 5.7). The yields were calculated in tons per hectare from different farmers with CA and without it. These results were also in agreement with those by FAO (2013).

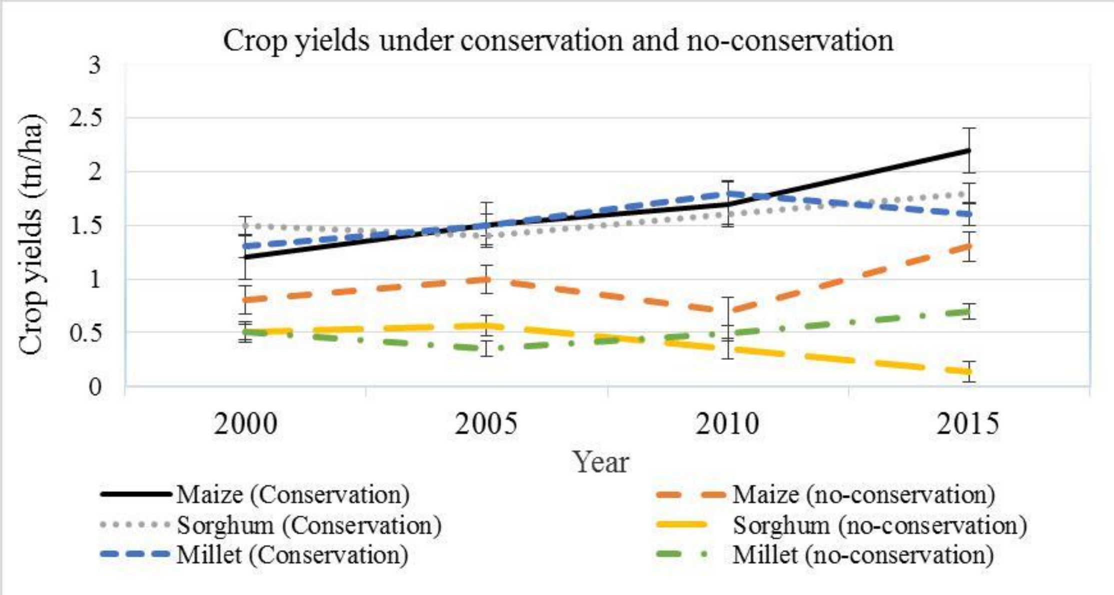

Figure 5.7: Variation in crop yields under conservation and no-conservation from 2000 to 2015 (5-years averaged data) in the Mnyakongo and Ugogoni villages of the Kongwa District, a semi-arid zone in central Tanzania. Vertical bars indicate the standard error of the means (n=4). **Source:** Field Survey Data, 2016

The findings of the present study has revealed that maize, sorghum and millet yields were significantly greater (1.7 tn ha^{-1}) under CA than (0.7 to ha^{-1}) without CA (Figure 5.7). Maize which is a preferred food crop in the country, its yields increased from 1.3 tn in 2000 to 2.3 tn ha^{-1} in 2015. Further, its yields were even more when intercropped with leguminous crops. In farms without CA, maize yields trailed from 0.8 tn ha^{-1} in 2000 to more than 1 tn ha^{-1} in 2015. Thus, there were significant differences (P <0.05) between the two scenarios in terms of yields.

5.4 Discussion

5.4.1 Conservation Agriculture

The results from analyses revealed that despite the significance of CA to both crop yields and environmental conservation, its adoption at both local and national level is very low. This reflects the continental (Africa) trend where CA is less adopted and predominantly under small scale. Crop rotation and little tillage were optimally adopted than other forms in terms of acreage (Figure 5.4).

However, the rate of adoption was significantly greater in mulching (Figure 5.5) which was adopted at R^2= 0.95, followed by crop rotation, agroforestry and little tillage at 0.90, 0.68 and 0.57 respectively (Figure 5.4 and 5.5). The CA with high acreages (Figure 5.4) had been in practice for a couple of years while mulching and agroforestry (Figure 5.5) appeared to be new techniques, however, the latter received high attention from the adopters (farmers).

Literally, Table 5.2 indicates that Ugogoni Village had high ratio of the farmers who asserted CA to have been effective in their area. Considerably, agroforestry was more practiced in the village than in the counterpart (Mnyakongo Village) and this was attributed by its proximity to some forests and being located in the lowland. Therefore, most farmers made use of these ecological potentials. Time factor had significant influence in the CA adoption as some laggards did so after some couple of time. The findings indicate that the household always adopt new agricultural technology when the benefit of the new technique is significantly greater than that of the existing technology.

This utility based adoption approach was also observed by Heckman (1979), Rogers (1995) and Mwaseba *et al*. (2006). In the study area, 150 respondents specifically adopted CA because they wanted higher yields, while 65 and 60 did so to conserve soil fertility and soil moisture, and control erosion respectively. Few 45 and 20 farmers opted for CA to reduce frequent labor work and related activities respectively (Figure 5.6 and Table 5.3).

Most households adopted CA after a careful decision based on the trade-off. These results are in agreement with Thierfelder *et al*. (2012), Ngwira *et* al. (2014) and Kimaro *et al*. (2015) who had similar observation in other countries from Sub-Sahara Africa. Since the rate of CA was mainly hypothesized against the desire for higher yields, preservation of soil moisture and fertility, control of soils erosion, and reduction of labor work; this study has significantly confirmed that the majority farmers opted CA for higher yields.

Despite not being an extreme labor demanding practice, it was noted that labor shortage hampered the CA adoption to some extent. This was critically caused by rural-urban migration amongst the working class in search for employment and wage labor. As a result, agricultural practices in most rural areas remain under the dependent class (children and old people) who are less energetic. To some extent agroforestry was less affected by this migration compared to other CA forms as it mostly involves perennial crops that may not demand frequent labor (Hong *et al.,* 2018).

Through interviews and discussions, most agricultural officers acknowledged to have been proposing several CA practices; however, financial constraint has been a major limiting factor to pay regular farms visits especially in remote areas. Despite the financial constraints, this study realized that the adoption of CA practices may solely depend on skills, interest, awareness and priorities of the adopters (i.e. early, moderate and laggards). However, to enhance CA adoption in the study area and the country at large; agricultural and extension officers should pay adequate visit to advice farmers on different agronomic practices that can optimize yields and elevate environmental services.

This is important because at farm level, some farmers blamed agricultural experts for not giving substantial extension services. This means, despite the farmers' willingness to adapt, if there will be no extension support, obviously the adoption rate will slow down. This is because their indigenous knowledge may not be enough to suffice climate turbulence. During the series of discussions, an anonymous farmer claimed that agriculture is meant for the poor. He further justified that most of the officers/experts do not engage in it, instead they prefer other clerical jobs. His claims were associated with many government reports that indicate that 70% of agricultural industry in the country is under smallholder farmers who are mostly economically deprived.

On the basis of such premise, this study suggests that; agricultural and extension officers should instill a sense of awareness and confidence among farmers on the understanding that, agriculture is a respectable industry and thus, whoever can go for it regardless his/her economic status. This can contempt the long standing local joke *"mkulima"* a Swahili saying that mean "a poor" as associated to agriculture. Here, they meant that agriculture is for the lowest class and jobless people. Even the government has always been asking and requesting jobless people especially in town to join agriculture industry for their survival and development.

5.4.2 Crop Yields

The influence of CA on crop production has been substantially revealed. As from the year 2000 to 2015, the yields of sorghum and millet were significant greater under CA (1.5-1.8 ha^{-1}) and (1.3-1.6 ha^{-1}) than without CA (0.2-0.5 ha^{-1}) and (0.5-0.7 ha^{-1}) respectively (Figure 5.7). Of the two crops, sorghum yields had significant variation between the farms with CA (1.8 tn ha^{-1}) and without it (0.2 ha^{-1}) compared to millet which varied from (1.6 ha^{-1}) with CA to (0.5 ha^{-1}) without CA (Figure 5.7).

Thus, for optimal yields, the CA practices need to be more integrated in sorghum than millet production. These results are in agreement with the studies by Dixon *et al*. (2001), Glaser *et al.* (2001) and Kimaro *et al*. (2015). The yields increase has been significant in limiting the level of hunger in the area. Moreover, CA gave optimal yields when integrated with irrigation and organic fertilization. Therefore, the incorporation of these aspects in CA is worthwhile to elevate crop yields in the area.

On the other hand, the increasing demand of organic food at global market may increase the adoption of CA (organic farming) in various countries (FAO 2013). While other parts of the globe have considerably adopted CA, Africa has not yet done well in those aspects (See Figure 5.1). Thus, compelling measures and emphasis are required in the continent to increase this adaption (Mkonda and He 2017a & 2017b).

Extensively, this will enhance the adaptive capacities among the smallholder farmers and limit the level of vulnerability from the global and local environmental change (Paavola 2008; Challinor *et al*., 2014; Mkonda and He 2017b). Thus, while proposing the increased CA adoption at local level and in various agro-ecological zones, it is also adequately advocated its adoption at national, regional, continental and global level because mitigation measures can have global impacts than locally.

5.4.3 Irrigation

With respect to the semi-arid areas, CA observed to work properly through irrigation. It mainly safeguards soil fertility and moisture and thus, improving agro-ecosystems tenable for crop production and environmental conservation. Despite the fact that irrigation was limited to small area (about 5814 hectares i.e. <5% of the total area) located near Mseta, Mzeru, Mlanga, Ikoka and Chelwe rivers (Figure 1.1 in Chapter One), it had significant contribution to yields and conservation.

However, Water User Association (UWA) and/or Irrigators Organization (IO) which control irrigation operation in the area encountered multiple challenges. Among these were water use conflicts, destruction of irrigation infrastructures and financial constraints whereas, all these challenges posed some consequences. This small area under irrigation denies the exploitation of a wide range potentials associated with irrigation.

This problem is also acute at national level where less than 4% of the total irrigable land potentials has been harnessed (URT 2012; 2013). According to the zonal irrigation engineers, the area has abundant ground water which could be the best option, but this potential has not yet been made into use. He further clarified that various geophysical surveys have indicated that most ground water is located at less than 60 meters deep. This is quite contrary to the countries like China where this depth can exceed 200 meters.

As a way forward, the substantial investment in technology is very important for exploitation of both ground and rain water. As a trial and error, during rains some farmers collect running water from seasonal rivers for spate irrigation. This water is intended to be reserved and used during water stress. However, due to weak infrastructure, the loss of this water is critically high. Thus, good mechanisms are required to boost their local innovations.

5.4.4 Fertilization

Fertilization has significant contribution to CA as it increases crop yields. CA gives optimal advantages when integrated with fertilizations (Kimaro *et al.*, 2015). The present study found that, majority (62%) of the farmers do not use any fertilizations in their farms, however, 80% of those (38%) who use it, applied organic fertilizers while few (20%) used chemical fertilizers.

It was realized that most organic fertilizers come from straw and animal manure. Much of animal manure came from goats, sheep, cattle, pig and donkeys. In terms of amount, most farmers were assertive that, for optimal crops yields, they required at least

5000-10000kg ha^{-1} of organic fertilizers whose fertility could remain in the farm for 5 years.

On the other hand, chemical fertilization such as DAP, NPK, SA, TSP and UREA were applied in few areas especially under irrigation schemes. This is because the Ministry of Agriculture, Livestock and Fishery (MALF) recommends chemical fertilizers under irrigation schemes as it does well under constant soil moisture than in a mere drought areas (i.e. where evaporation is high). The MALF through the department of agricultural inputs has been providing inadequate share of chemical fertilizers to Dodoma Region i.e. 1x104. That means, only 4000 hectares could be fertilized in the whole region. In that share, Kongwa District received <2,000 vouchers that ended fertilizing very few hectares. However, it increased crop yields to 7.2 tn ha^{-1} (from less than 3 tn ha^{-1} without it).

Overall, this study realized that; for successful CA, there is an immediate need to attach irrigation and fertilization for sustainable conservation of soil moisture and fertility. It was also realizable that, CA offered economic and socio-ecological advantages to the farmers depending on the biophysical environment. Areas under irrigation schemes that received chemical fertilization provided favorable conditions for crops production.

5.4.5 Environmental Sustainability

The study by FAO (1988) showed that chromic luvisols with a sandy loam texture is among the dominant soil types in the area. Soil types are among the most important factors that control several biological processes in the particular locality. It was observed that silt contents in different farms were not significantly different ($P > 0.05$) and ranged between 170 and 255 g kg^{-1} soil while a bulk density ranged between 1.11 and 1.35 Mg m^{-3} under CA and without it respectively (Bationo *et al*., 2006). Soil carbon ranged from 1-1.22 Mg C ha^{-1} (0-20 cm deep) under CA and declined in farms without CA while calcium, magnesium and sodium ranged from 0.5 to 4 Mg ha^{-1} under CA (Glaser *et al*., 2001).

In most areas, the soils had neutral pH values ranging from 5.40-6.10 on the top soils (Glaser *et al*., 2001; Bationo *et al*., 2006). In addition, it had moderate high cation exchange capacity and high base saturation (Solomon *et al*., 2000). The CA practices appeared to optimize important soil nutrients i.e. soil quality in the area. Accordingly, soil nutrients were significantly greater (P <0.05) under farms with CA than that without it and there were significance difference between soils under CA and without it. The former was better in the optimization of environmental sustainability than the latter (Mkonda and He 2017d).

A vast number of studies that have been conducted in similar agro-ecosystems i.e. climate and soil types just to list a few, have also endorsed the positive roles of soils fertility and moisture (under CA) in elevating the biological functions of microorganisms in balancing the ecosystems (FAO 1988; Glaser *et al*., 2001; Bationo *et al.,* 2006; Kimaro *et al*., 2015). Mycorrhiza fungi also operate well under proper soil organic managements where it then increases the capacity of nutrients uptakes and resistance to pathogens by plants (Solomon *et al*., 2000). This situation improves the interaction between roots and microorganisms.

Moreover, a study by Haoa *et al*. (2016) further indicated that, no-tillage, crops rotation, mulching and agroforestry were the sinks of the top three greenhouse gases i.e. carbon dioxide (CO_2), methane (NH_4) and nitrous oxide (N_2O) and thus, conferring adaptation and mitigation. Now that, it is obvious that CA practices have multiple benefits to environmental sustainability (Linhard *et al*., 2013). Hence, CA practices have significant contributions to sustainable environmental conservation focusing on lithosphere, hydrosphere, biosphere and atmosphere.

Therefore, it is advisable to build the capacity of the smallholder farmers (i.e. who form 70% of Tanzanian agriculture) so that they can effectively integrate AC in their farming. If this integration will reach to at least 20% of the total farm size of every household will definitely increase crop yields and environmental services (2013). This will have long-term positive impacts in serving the present needs' of the people and environment without compromising the needs of the future generations (FAO 2012).

5.5 Conclusion

This study sought to explore the adoption rate of CA in Kongwa District, the semi-arid agro-ecological zone of Central Tanzania. It accepted the alternative hypothesis (H_1) because the CA adoption was greatly influenced by the famers' desire to achieve higher yields. Besides, retention of soil moisture, conservation of soil fertility, and control of soil erosion were among the contributing factors that attracted farmers to adopt CA. In both villages, it was realized that, there were correlation (P <0.05) between size of land under CA and total land under farming (Table 5.1).

Time factor was another determinant factor for the adoption trend as there has been an increase in hectares under CA as time goes. Despite of that, the present study has realized that by average CA is insignificantly practiced in the study area as <10% of the household were involved. Among the CA practices, mulching appeared to receive high attention to adopters as it was adopted at R^2=0.95. Little tillage appeared to dominate in acreage (about 6000 ha) than others. In addition, CA practices appeared to be more beneficial when supported with organic fertilizations and irrigation.

Animal manures and straw were the main source of organic fertilization. Further, this study found significance difference between the areas under CA and without it. Crops yields and environmental sustainability were optimal under CA than without it (Figure 5.7). Therefore, despite of being understandable that CA can improve the agricultural systems, it was recommendable to quantify such environmental potentials.

Thus far, the present study proposes the adoption of CA practices in various agro-ecological zones in Tanzania to manage agricultural soils, and attain socio-economic and ecological advantages. This is because CA confers adaptation and mitigation advantages. Likewise, effective livestock keeping should be integrated in various CA practices for mutual benefits. Subsequently, planners, policy makers, agricultural experts and other agricultural stakeholders and practitioners can consider these findings as among the good baseline in their future endeavors. Lastly, more proactive interventions and efforts are called from different stakeholders to join hand in this agenda. These efforts should mostly target the areas with extreme weather stresses.

There are however, a number of research priorities for further investigation need to tackle the following questions: (1) Characterization of people who are involved in CA (is it the small scale or large scale) and its policy implications? (2) What are the drivers that can influence the CA adoption in small-scale farming? (3) How has climate variability been influencing positively or negatively the adoption of CA especially during the extreme wet period as compared to the extreme dry period)? (4) How much does crops yield harvested from CA contribute to food security and economic welfare?

Chapter Six: General Discussion and Conclusions

6.1 Introduction

It is confirmed in the empirical chapters of this thesis that soil fertility and favorable climate are critical factors for smallholder's crops productivity in Kongwa District. The improvement of soil fertility and its sustainability depends on good agronomic practices. Similarly, the adoption of proper adaptation measures to climate change impacts has significant contribution in curbing the increasing environmental challenges. In the midst of food insecurity and abject poverty; the impacts of climate change, weak crop breeds and poor soil management are the pillar challenges to the majority smallholder farmers in many semi-arid areas.

This thesis thus, focused on organic fertilizations and its implications to soil carbon accumulation and related aspects (e.g. N, P and K), temporal climate variability trend with the earmarks on rainfall and climate. In addition, it assessed the temporal trends of maize, sorghum and millet production, and established the correlation between/among these variables. Lastly, it assessed the adoption rate, and potentials of conservation agriculture in the study area.

6.2 Methodology

Both qualitative and quantitative data were collected for the requirements of this doctoral thesis. Soils samples were collected in the two representative villages of Mnyakongo and Ugogoni basing on two soil depths (0-20 and 20-30cm). Moreover, this soil sampling was done in two soil treatments i.e. farms under organic and no-fertilizations. Climate data from the year 1980 to 2015 were collected from Tanzania Meteorological Authority and Kinyasungwe meteorological station in the study area, while crops (i.e. maize, sorghum and millet) data for the same duration (1980-2015) were collected from Kongwa District Council and the Ministry of Agriculture, Livestock and Fishery. Household surveys, informative interviews, physical observations, group discussions and literature reviews were important approaches for data collection.

Embarking to analyses, a wide range of methods and software were employed. SOC was analyzed following Walkley-Black Method. Total soil nitrogen was analyzed using modified Kjeldahl procedure. Soil pH was measured by glass electrode using soil to water ratio of 1:2. Then, the available phosphorus (P) was extracted using Bray 1 method and determined by spectrophotometric procedure. Exchangeable potassium extracted using neutral 1.0M ammonium acetate and estimated using of flame photometer.

Crops and climate analyses were done using Mann-Kendall Test, and Microsoft excel software. Socio-economic data from questionnaire survey were done through SPSS (version 20) software. Qualitative data were analyzed through theme content analysis and Community-based Risk Screening Tool-Adaptation and Livelihoods.

6.3 Main Findings of the Thesis

The main findings indicated that the accumulation of SOC was significantly greater in soils under organic fertilization (1.15 and 0.80 MgC ha^{-1} at soil depth 0-20 cm and 20-30cm depth) than under no-fertilization (0.35 and 0.30 MgC ha^{-1} at 0-20 cm and 20-30 cm) and decreased with increasing soil depths. So did the crop yields (1.7 tn ha^{-1} under organic fertilization vs. 0.6 tn ha^{-1} under no-fertilization). Thus organic fertilizations are the recommendable practice for optimizing SOC, soil fertility and crops yields (See Chapter 2).

On the other hand, the total annual rainfall or mean annual temperature (1980-2015) fluctuated at a decreasing trend (R^2 =0.22) or an increasing trend (R^2 =0.30). Meanwhile, crop yields of maize, sorghum or millet fluctuated at the decreasing trend at R^2=0.40, 0.35 or 0.11, respectively (See Chapter 3). In addition, there were significance correlations between rainfall variability and crops yields at R^2=0.53, 0.39 and 0.48 for maize, sorghum and millet respectively (Figure 4.2) while temperature correlated negatively at R^2=0.37, 0.30 and 0.33 with the yields of these crops (Figure 4.3) as see in Chapter 4. Overall, there is significant positive and negative correlation between the trend of crop yields and that of rainfall and temperature variability (P <0.05). However, there might have been other significant factors affecting the yields e.g. poor soil, crop diseases etc. but rainfall and temperature seem to have significant contribution to crops failure.

In terms of CA, little tillage, agroforestry, crops cover/mulching and crops rotation were respectively adopted at R^2=0.86, 0.66, 0.64 and 0.63 as CA practices (Figure 5.4 and 5.5) as seen in Chapter 5. Further, there has been significant correlation between the adoption of CA and crops yields (P <0.05). Yields for maize, sorghum and millet were significantly greater (1.7 tn $ha-^1$) under CA than (0.9 to ha^{-1}) without CA as seen in Figure 5.7 (Chapter 5).

Furthermore, maize yields increased from 1.2 to 2tn ha^{-1} when intercropped with leguminous crops. Besides of optimizing yields, CA serves as climate smart-agriculture as it mitigates climate change impacts by seizing greatest greenhouse gases i.e. CO_2, CH_4 and N_2O. CA operates well when integrated with organic fertilization and irrigation (Figures 5.8 and 5.9) in Chapter 5. More yields have been recorded when such integration is involved.

6.3.1 Climate, SOC and Crop Production

Basing on the results from soil analyses (Table 2.3, Fig. 2.1 in Chapter 2) the accumulation of Soil Organic Carbon (SOC) were decreasing with the increasing soil depths. Since the result is from the area with almost similar soil characteristics (not highly varied), the influence of soil water in the deposition of soil nutrients i.e. SOC was observed. Similarly, the influence of soil temperature was seen in the decomposition of organic matter to form soil nutrients.

This science on the influence of temperature in the decomposition, mineralization and immobilization of nutrients is confirmed in various studies. On the other hand, the accumulation of SOC increases soil fertility for crops production and therefore, had significant contribution to crop yields in the area. In this science, the three aspects: SOC, climate and crops production had linkages. They form a cycle as they almost depend on each other. Rainfall and temperature facilitate the decomposition of organic matter and subsequently SOC is accumulated. SOC plays a great role in carbon sequestration and increases fertility to increase crops yields. Similarly, its accumulation depends on the decomposition of organic matter including crops straws (detailed in Chapter 2).

The impacts of climate change had significant contribution to accumulation of SOC in the study area. Excessive droughts which has been recently occurring in replicate, has also affected the production of plant biomass supportive for organic matter formation and accumulation of SOC. Besides, most biological processes cannot operate efficiently under stressed environment. For example, microorganisms like mycorrhizae fungi operate in the context of environmental friends. In addition, environmental stress brings about shortage of crops residual, humus, mobilization, decomposition and soils mineralization which are significant in SOC accumulation.

Generally, the correlation of these variables between climate variability versus crops yields, SOC versus crops yields and climate versus SOC was found and established. . The decrease in rainfall decreases crops yield and vice versa, the increase in temperature decreases crops yields and vice versa, the increase in SOC increases crops yields and vice versa, and for SOC to accumulate it needs favorable climate. Therefore, change in climate effects to both crops yield and SOC in the study area.

6.4 Adaptation Strategies to Climate Change Impacts

Basing on the existing knowledge in the study area and the scientific knowledge from research findings, this study has proposed a district adaptation plan that involves a wide range of adaptation strategies to reduce at maximum the vulnerability of smallholder and/or medium scale farmers Table 6.1 below and Table 4.5 in Chapter four (4).

Table 6.1: Proposed Adaptation Plan for Kongwa District

1. Promoting and strengthening the use of improved seed varieties of the major food crops i.e. maize, sorghum and millet.
2. Improving and supporting Good Agronomic Practices (GAP) in the area.
3. Drilling ground water to expand irrigation systems.
4. Promoting and supporting the availability and applications of organic and inorganic fertilizers.
5. Strengthening weather information system among the communities.
6. Enabling Rainwater Harvesting (RWH) technologies among the communities.
7. Promoting Conservation Agriculture (CA) in the area.
8. Facilitating more extension services in the area.

Source: Field Survey Data, 2016.

Table 6.1 above has incorporated the most important/useful adaptation plan at district that can be implemented at cheap cost. Thus, its adoption is the most significant. Description is hereunder:

i. Promoting and strengthening the use of improved seed varieties of the major food crops

This adaptation plan aims at increasing crop yields per unit area (ton per hectare). The improved seeds should be drought resistant and short maturing. For example, STUKA, TMV and STAHA for maize. The increase in crops productivity will enhance food security, boost income and raise the welfare of the household. To implement this plan, it is expected that adequate extension services, varieties of crops breeds and other relevant agricultural inputs should be in place.

District agricultural officers will be the coordinators of this plan. It is a role of the central government, district and other development partners to fund the implementation of this plan. The planners and decision makers should adopt the cost-effective plan in order to easily attract funds.

ii. Improving and supporting good agronomic practices in the area

Soil organic management has significant contribution to the increase in crops yield and food security. The increase in crops yield can be achieved by increasing the number of extension and agricultural officers in the area. The use of Farm Field School as demonstration plots creates awareness and arouses more interest to farmers in the adoption of potential agronomic practices. The Ministry of Agriculture is responsible in hiring more extension and agricultural officers while the district needs to create favorable condition for these experts to work. The central government, development partners and other funders need to support the implementation of the plan by funding it.

iii. Drilling ground water to expand irrigation systems

Recently, irrigation has been implemented in a very small area of the district i.e. in irrigation schemes along the rivers (Figure 1.1 in Chapter One). Findings show that Dodoma is among the most endowed regions with high quantity of ground water. Since the aim of this plan is to increase crop productivity through irrigation (i.e. small scale), harnessing of the ground water is inevitable; this will increase crops yields of various crops.

Using that water resource, smallholder farmers can undertake agriculture at any time including in the dry season. Feasibility study should be done to establish actual points of drilling. Financial and personnel resources should also be mobilized. Ministries of Agriculture and Water should be the heart of implementation. The central government and development partners have to fund the implementation of this project.

iv. Promoting and supporting the availability and applications of organic and inorganic fertilizers

Soil fertility is increased through organic and inorganic fertilizations. Organic fertilizations from animal manure, straw etc. should be highly encouraged as it serves multiple roles ranging from increasing soil fertility to carbon sequestration. Chemical fertilizers should be equally advocated in the area by increasing the quantity. This can be done by increasing and strengthening subsidies for agricultural inputs.

Results from soil analyses should guide the type of fertilization to be applied, and application should just target to increase the deficient nutrients. Demonstration plots through Field Farm School (FFS) should be established to create more learning and understanding among the farmers. The District and Ministry of Agriculture should be responsible for the implementation of this plan. The central government needs to fund the plan from its budget.

v. Strengthening weather information system among the communities

This plan aims at creating awareness to farmers on the decision and timing of farming. This plan is quite important because recently the rainfall trend has been unrealistic, unreliable and erratic therefore, the onset and cessation cannot be easily determined. In this respect, weather information should be incorporated by farmers in their day to day farming activities.

To attain this plan, Tanzania Meteorological Agency (TMA) and local meteorological stations should be strengthened to produce a reliable weather forecasting. Weather information can be communicated to farmers in a number of ways including village meeting, mobile phone etc.

A number of authentic weather stations should be installed in the area with some training on how to use these stations. TMA should be responsible in establishing standard of the weather station and information. The government and other development stakeholders have to fund the implementation.

vi. Enabling rainwater harvesting technologies among the communities

This aims at increasing and ensuring the availability of water resources for irrigation and other domestic uses. Despite of proposing the drilling of wells for small scale irrigation, rain water should be equally harnessed. Through rainwater harvesting (RHW), farmers can expand irrigation from the home stead garden to a large farm. At the preliminaries, identification of existing and potential water harvest technologies should be done.

The existing technologies which are good should be up-scaled. In this aspect, the Ministries of Water, and Agriculture should be the main concern at ministerial level. Similarly, the Dodoma zonal irrigation scheme, district agricultural officers and other water harvesting experts will be the key coordinators of the plan. Again, the central government and development partners should be the source of funds.

vii. Promoting conservation agriculture in the area

Conservation Agriculture (CA) aims at conserving both soil moisture and fertility. Subsequently, this increases the productivity of crops to ensure food security and improved livelihoods in the area. Identification of the existing CA practices in the area should be done prior proposing the new ones. The CA which is environmental friendly should be up-scaled in the area. Creation of awareness on the newly devised CA practices should be equally done to increase the rate of adoption.

Significantly, CA practices are desirable because they can serve as Climate Smart Agriculture (CSA) in the area. Agricultural and extension officers should operate this plans and Field Farm School should be demonstrated as well. Agricultural universities and institute i.e. Sokoine University of Agriculture should be adequately involved at service and consultancy level. The government and other development partners should be involve in funding the implementation of this plan.

viii. Facilitating more extension services in the area

Extension services have significant contribution to crop productivity in the area. However, the current extension services are limited due to shortage of both human and financial resources. Since we aim to boost crop productivity, food security and people's livelihoods, we have to facilitate the operation of these services. This can be through increasing agriculture experts as well as giving adequate financial resources. The government through the Ministry of Agriculture has a significant role to play in the implementation of this plan, especially hiring of the extension officers and giving financial support.

6.5 Discussion

Significant accumulation of SOC under organic fertilizations reveals the influence of organic manure in soil fertility. Fortunately, farms under SOC gave more yields than those without it. Besides that, SOC is capable in the mitigation of climate change impacts by seizing greenhouse gases. Therefore, SOC was the best proposition for optimization of crops yields and environmental services.

Climate change and variability has been taking place in the study area, and this is evidenced by both the results from scientific analyses and perceptions of the local communities as confirmed by the present study. Local experiences and perceptions on the decreasing rainfall and increasing temperatures are clearly supported by metrological data that demonstrate decreasing rainfall and increasing temperatures.

However, the major concern of the community was the variability in rainfall amount, timing and number of wet spells. They perceived that decreasing rainfall is a major cause of reduced crops yields. The distribution of wet spells in the area has been hindering the crop growth in the area.

On the other hand, the community awareness and experiences on the trends of crops production (i.e. maize, sorghum and millet) had correlation with the results from statistical analyses. Overall, the two sources asserted the decreasing crops yield in the area. Climate change impacts have significantly affected crops yields (Chapter 4). Majority of farmers were interested in maize for food but, unfortunately, maize was the most vulnerable crop compared to sorghum and millet (Figure 3.3 – 3.5). Thus, the failure in maize yields had a serious consequence to the people.

Therefore, the diminishing crops return from the field has increased the magnitude of other non-climate stressors like land conflict, poverty and degradation to be at maximum (Mkonda and He 2017d). The changing climate has affected the entire livelihood of the poor communities who entirely depend on rain fed agriculture. Reduced crops yield has increased food insecurity and poverty in the area. Farmers have adopted some adaptation strategies in their farming systems to curb the situation. They use their indigenous knowledge and some scientific expertise (Table 4.5).

Despite of this small scale adaptation by smallholder farmers to climate impacts; more information on climate-change adaptation is necessary to enhance and facilitate local adaptations. This is significant because we are in the era of changing climate. Although it is evident that climate is changing, it’s realistic especially on the magnitude of change and impacts to small holders farmers is not yet well establish across the country. That is why even the adaptation plan bases on local scale assuming this spatial variation of climate impacts.

6.6 Conclusions and Recommendations

In conclusion, this study demonstrated how SOC accumulated under different soil managements. It revealed that organic fertilizations had significant contribution to SOC accumulation. Similarly, the accumulation of SOC were higher at 0-20cm in both soils under organic and no-fertilizations. In addition, SOC were higher under organic fertilizations than under no-fertilizations.

In terms of climate, this study found that from 1980 to 2015 temperature has been fluctuating at an increasing trend contrary to rainfall which has been fluctuating at a decreasing trend. Similarly, the trends of maize, sorghum and millet yield have been behaving like rainfall. The influence of climate in SOC accumulation was revealed as high rainfall and moderate temperature influenced the production of biomass, organic matter and SOC. Generally, climate has influence to crops production and SOC and vice versa.

To increase the production of maize, sorghum and millet, we need to enable smallholder farmers to adopt compelling adaptation measures that will even enhance their resilience to climate change impacts. Increased irrigation, adoption of drought resistant crop varieties and soil fertilizations (organic and inorganic) are among the adaptation measures. These will increase crop production, increase food security and alleviate poverty.

The use of improved seed like TMV-1, Stuka M1, Staha, TAN 250 and Kilima (for Maize) should be applied. Similarly, *Macia* for sorghum and *bulrush* for millet are the resilient cultivars that should be equally adopted. Further, seeds genoplasms should be well engineered to get the most tolerant seeds that can withstand the increasing climatic stresses.

Despite the significant influence of rainfall and temperature on maize, sorghum and millet production; the influence of non-climatic factors such as soil management, agronomic practices, labor and capital just to mention a few could not be underrated. Among these, soil fertility was degraded by continuous cultivation without fertilization. This situation affected other biological functions of the soils. Thus, poor soils fertility brought about poor yields and environmental services.

6.7 Way Forward

Given the community vulnerability due to climate change impacts, this study calls for more proactive action interventions to curb the problem. For instance agroforestry (afforestation) that is tenable for yields optimization and acts as Clean Development Mechanism (CDM) to attempt an important goal of the Kyoto Protocol of 1997. This in addition works along with the Emissions Trading (ET).

Among other thing, this intervention will build and enhance the resilience of these vulnerable communities. The adoption of adaptation options should be done basing on the local context. There is a need to pilot and upscale the most suitable adaptation option for a wider and successful up-taking by the farmers in the area. There is a need to guide farmers on the choice of quality seeds varieties. In short, irrigation, fertilization and adoption of improved heat and/or drought resistant seeds should be done.

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Publications

This thesis is constituted by the following published papers and book chapters

1. **Mkonda, M.Y**., He, XH. (2018). Accumulation of Soil Organic Carbon and the Related Variables under Organic and No-fertilizations, and its influence to crop yields in Tanzania's Semi-arid Agro-ecological Zone. *Ecosystem Health and Sustainability*. Volume 4(2); Doi:10.1080/20964129.2018.1463146.
2. **Mkonda, M.Y**., He, XH., Festin, E.S. (2018). Comparing smallholder farmers' perception of climate change with meteorological data: Experiences from seven agro-ecological zones of Tanzania. *Weather Climate and Society*. Volume 10 (3); Doi: 10.1175/WCAS-D-17-0036.1.
3. **Mkonda, M.Y**., He, XH. (2018). Climate Variability, Crop Yields and Ecosystems Synergies in Tanzania's Semi-arid Agro-ecological Zone. *Ecosystem Health and Sustainability*. Vol. 4 (3); Doi: 10.1080/20964129.2018.1459868.
4. Hong, Z., **Mkonda, M.Y**., He, XH. (2018). Conservation Agriculture for Environmental Sustainability in A Semi-arid Agro-ecological Zone under Climate Change Scenarios. *Sustainability*. Vol. 10 (5), 1430; Doi: 10.3390/su10051430.
5. **Mkonda, M.Y**., He, XH. (2018). Vulnerability Assessment of the Livelihoods in Tanzania's Semi-Arid Agro-Ecological Zone under Climate Change Scenarios. *Climate*. Vol. 6 (27); Doi: 10.3390/cli6020027.
6. **Mkonda, M.Y**., He, XH. (2018). Soil Quality and Agricultural Sustainability in Tanzanian Semi-arid Agro-Ecological Zone. In: Sustainable Agriculture Reviews, Lichtfouse ed., Springer International Publishing, Switzerland (Accepted).
7. **Mkonda, M.Y**., He, XH. (2017). Are Rainfall and Temperature Really Changing? Farmer's Perceptions, Meteorological Data, and Policy Implications in the Tanzanian Semi-Arid Zone. *Sustainability*, Vol. 9(8) 1412; Doi: 10.3390/su9081412.
8. **Mkonda, M.Y**., He, XH. (2017). Yields of the Major Food Crops: Implications to Food Security and Policy in Tanzania's Semi-arid Agro-ecological Zone. *Sustainability*, Vol. 9(8), 1490; Doi: 10.3390/su9081490.
9. **Mkonda, M.Y**., He, XH. (2017). Conservation Agriculture in Tanzania: Sustainable Agriculture Reviews. Journal of Sustainable Agriculture Reviews. Springer. Reviews. Vol. 22; Doi: 10.1007/978-3-319-48006-0-10.

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11. **Mkonda, M.Y**., He, XH. (2017). The Potentials of Agroforestry Systems in East Africa: A Case of the Eastern Arc Mountains of Tanzania. *IJPSS*, 14(3): pp 1-11.

12. **Mkonda, M.Y**, He, XH. (2017). The Emerging Population Increase and Its Environmental Challenges and Remedies in Iringa Municipal, Tanzania. *JGEESI*, 9(2): pp 1-11.

13. **Mkonda, M.Y**., He, XH. (2017). Sustainable Environmental Conservation in East Africa through Agroforestry Systems: A Case of the Eastern Arc Mountains of Tanzania. *International Journal of Sustainable and Green Energy* 6(4): 49-56.

14. **Mkonda, M.Y**., He, XH. (2017). Tanzanian Controversy on Resources Endowments and Poverty. *Environment and Ecology Research,* 5(1): 29-37; Doi: 10.13189/eer.2017.050104.

15. **Mkonda, M.Y**., He, XH. (2016). Efficacy of Transforming Agriculture for Survival to Commercial Agriculture through *'Kilimo Kwanza'* Initiative in Tanzania. *Natural Resources and Conservation* 4(4): 43-50; Doi: 10.13189/nrc.2016.040401.

16. **Mkonda, M.Y**., He, XH. (2016). Stocks and Ecological Significance of Soil Carbon in Tanzania. *Natural Resources and Conservation* 4(3): 42-51; Doi: 10.13189/nrc.2016.040302.

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Appendixes

Appendix 1: Household Farmers' Questionnaire

Introduction

I Msafiri Yusuph Mkonda, a lecturer from Sokoine University of Agriculture in Morogoro, Tanzania who is currently a PhD candidate at the Centre of Excellence for Soil Biology, College of Resources and Environment, Southwest University, 400715, Chongqing. China, is conducting research on the "***Soil Organic Carbon Accumulation, Climate Variability and Crop Production in Tanzania's Semi-arid Agro-Ecological Zone: A Case Study of the Kongwa District"*** The overall objective of his study is to assess the accumulation of soil organic carbon under different soil treatments, assess the variability of rainfall and temperature, and assess the production temporal production trends of the major food crops. The study is implemented in selected areas of Semi-Arid Lands Agro-ecological Zone, Tanzania

.SECTION A: BACKGROUND INFORMATION

1. Name of the District ---
2. Name of the ward---
3. Name of the village---
4. Name of sub-village---
5. Name of the head of household--
6. Sex: 01 Male 02 Female
7. Age of household head---
8. Marital status: (a). Single, (b). Married, (c). Divorced. (d)Widow. (e). Separated
9. Household size.
10. Level of education of household:
    a. No formal education b. Primary education, c. Secondary education,
    d. Post-secondary education e. Others (specify)
11. Place of origin: (a). Born in the village (b). Born outside the village but within the district (c). Born outside the district but within the region (d) Born outside the region (e) Born outside the country
12. If you moved into this village, when did you settle in this village...? (year)

SECTION B: PERCEPTION OF CLIMATE CHANGE, PATTERNS AND INDICATORS

14. What do you understand by the term climate?
    a. Rainfall (1. Yes, 2. No), b. Temperature (1. Yes 2. No)
    c. Humidity (1. Yes, 2. No) d. Drought (1. Yes 2. No)

e. Wind (1. Yes, 2. No) f. Others specify (1. Yes, 2. No)

15. Are you aware that climate has changed or is changing? (1. Yes, 2. No)
16. What is the trend of rainfall during the last 20 years? (Tick as appropriate)
    (a) Increasing, (b) Decreasing, (c) Fluctuating, (d) No change, (e) Do not know
17. Have you observed any changes in temperatures during the last 20 years (Tick th appropriate) 1. Yes 2. No
18. If yes, what kind of changes: 1. Increasing 2. Decreasing
    Do not know--

SECTION C: IMPACTS OF CLIMATE CHANGE ON CROP PRODUCTION

19. What crop does your household grow and for what purpose (Tick all that apply)
    (a) Maize 1. Food, 2. Cash, 3. Food & Cash, 4. Do not grow
    (b) Sorghum 1. Food, 2. Cash, 3. Food & Cash, 4. Do not grow
    (c) Rice 1. Food, 2. Cash, 3. Food & Cash, 4. Do not grow
20. Historical patterns of crop production (per acre, during the last 20 years)
    (a) Maize 1. Increasing, 2. Decreasing, 3. Fluctuating, 4. Do not know
    (b) Sorghum 1. Increasing, 2. Decreasing, 3. Fluctuating, 4. Do not know
    (c) Rice 1. Increasing, 2. Decreasing, 3. Fluctuating, 4. Do not know
21. Has there been any change in types of crop grown by your household for the last ten years? (Tick as appropriate) 1. Yes 2. No
22. If yes, mention the new crops adopted?
    Reasons for adopting new crops;
23. Also, if yes, mention the crops abandoned
    Reasons for abandoning these crops;
24. What are other reasons for crop failure apart from impacts of CC&V?

SECTION D: FOOD ACCESSIBILITY, CONSUPTION PATTERNS, AVAILABILITY AND COPING MECHANISM

25. What are the major sources of food for your household consumption? 01 Own crops, 02 from relative, 03 Markets, 04 others (specify)
26. Is there any change of what you eat nowadays compared to what you used to eat in the past 20 years ago? 0. Yes 02. No
27. If yes, what are changes?
28. Do you or one of the household members sometimes collect fruits, leaves, roots, or anything from the bush for eating: 0 1 Yes 02 No
29. If yes, what types of products are you collected from the bush and eat in your Household:
30. What is the present situation in relation to the availability of edible products from the bush compared to the past 20 years: 01 Increased 02 Reduced
31. In which month do you plant your crops?
32. In which month do you harvest your crops?

33. How much did you store during the last crop season?
34. Was it enough to keep the family growing until next harvest?
35. If no, when did you exhaust your stock? months after harvest
36. Is there any changes in the amount of food produced at present compared to the past 20years ago? 1. Yes 2. No
37. If yes, what are those changes? 01 Increased, 02 Decreased, 03 Same, 04 Fluctuates
38. What is the major reason for the above "' .
39. Have you ever been faced with the problem of food shortage for the last 20 years?
40 If yes, in which months did it happens?
41. How does food shortage occurs? 01 Often 02 Sometimes
42. What are the main causes of food shortages in your household (Tick all that apply)
    (a) Drought. 1. Yes 2. No, (b) Flood 1. Yes 2. No
    (c) Too much rain. I. Yes 2. No, (d) Too low temperature 1. Yes 2. No
    (e) Too high temperature. 1. Yes, 2. No, (f) Strong wind I. Yes 2.No
    (g) Low soil fertility 1. Yes 2. No, (h) Weeds 1. Yes 2.No
    (i) Crop pest. l. Yes 2. No, (j) Crop pest. l. Yes 2. No
    (k) Crop disease. I. Yes 2. No, (l) Livestock disease I. Yes 2.No
43. What do you do if there is food shortage in your household?
    1. Buying, 02 Casual labour, 03 Borrowing, 04 Remittances, 05 others (specify)
44. How do you prevent food shortage in your household?
45. How do you store your farm produce after harvest? 01 Granary, 02 Bags, 03 Others?
46. What do you consider to be the major storage problems?
    1 Insect pest, 02 Fungus, 03 Rodents, 04 others

SECTION E: CONSERVATION PRACTICES AND ARTIFICIAL FERTLILIZATION

47. What is your farm size? 1. <one acre 2. >one acre
48. What type of fertilization do you use? 1. Organic fertilizer 2. Chemical fertilization
49. Iforganicfertilizer;whatarethose?
    Mention……….,………,……..,……..,………
50. Where do you get those organic materials 1. From animals 2. From plants
51. Can you make yourself those materials 1. Yes 2. No
52. Do they increase crop production when applied? 1. Yes 2. No
53. How long does organic manure keep soil fertility 1. Within 10 yrs 2. Above 10 yrs

54. If Yes to what extent do they increase in bags? 1. <5bags per acre 2. >5bags per acre
55. What amount of organic fertilizer can be enough to your farms? 1. <200kg 2. >200kg
56. What do you want the government to do to improve organic fertilization 1. Give loans 2. Give foods
57. If chemical fertilizer; what amount you need 1. 50kg 2. 50kg
58. Chemical fertilization is for 1. Planting 2. Growth 3. Others
59. Do you afford the costing price 1. Yes 2. No
60. How long have you been using chemical fertilization 1. Within 10 yrs 2. Above 10
61. Do you have water sources in the area? 1. Yes 2. No
62. Do you use that water for irrigation? 1. Yes 2. No
63. Do chemical application in the farms pollute water sources? 1. Yes 2. No
64. If yes how 1. Water runoff 2. Other agents

THANK YOU FOR YOUR COOPERATION

Appendix 2: Checklist for Focus Group Discussion

A. Focus Group Discussion

Elderly people who have lived in the village for at least 20 years

B. Crops and its biodiversity

1. What are the Crops grown in the area?
2. What are the Crops used to be grown but no longer existing?
3. What are the reasons of extinction of such crops?
4. What are the recently established crops?
5. What are the reasons for their adoption? 6. What is the production trend of key crops in the last 20 years?

C. Growing Season

1. What are the growing seasons during the last 20 years?
2. When used to plant and harvest?
3. Is there any change on plants and harvest dates?
4. What might be the reason for any change?

D. Rainfall and Drought

1. What is the trend of rainfall during the last 20 years?
2. When did you have unusual Rainfall/drought events?
3. What coping Strategies in place in case of drought or excessive rainfall?
4. How do you deal with inter-seasonal dry spell especially during? January and February?

E. Conservation agriculture and fertilization

1. Is conservation agricultural practice done in the area?
2. If yes what are those?
3. What are the dominant types of chemical fertilization applied in the area?
4. Do most people afford it?

F. Information and Communication

1. How do you access to information on weather?
2. Have you received any information on climate change in your village?
3. Have you received any information on drought or flood before they occur? If yes who provided that information?

G. External Support

1. Is there any local or International external Support in your village?
2. How important is such support to addressing issues of drought and floods?
3. How important is such support to solving environmental problems?

THANK YOU FOR YOUR COOPERATION

Appendix 3: Checklist for Key Informant

Biodata

Title---
Institution--
Education Level---

Questions:

1. What is the staple food of the people in your area?
2. What is the trend of key crop yields in your area for the past 20 years?
3. Is there any changes in rainfall and temperature in your area for the past 20 years?
4. If Yes, what kind of changes, increasing or decreasing? (i)Rainfall (ii) Temperature
5. How the peasants and farmers adapt to the variations in climate if there is?
6. Is there any relationship between the decrease in temperature and the fall of crop yields?
7. If there is? What kind of relationship?
8. If there is crop failure in the key crops which are the main source of staple food, how people supplement this deficit for their survival?
9. What are other factors apart from climate change affecting negatively the production of food crops?
10. Do people rely on forest food as one of their coping mechanisms toward food shortage?
11. If yes, what kind of forest foods, are these forest food also affected by the impacts of climate change and variability?
12. Is there any other adaptation measures by the people toward food scarcity in your area? If yes what are those?
13. What are the conservation agricultural practices done in area?
14. What are the sources of organic fertilizers?
15. Are there water sources in the area?

THANK YOU FOR YOUR COOPERATION

Appendix 4: Laboratory analysis

Analysis of soil properties such as carbon, nitrogen, soil pH, potassium, etc. was done in the laboratory of the Department of Soil and Geological Sciences, Sokoine University of Agriculture, Tanzania.