EFFECTS OF CONSERVATION AGRICULTURE ON SOIL FERTILITY OF SMALLHOLDER FARMERS' AGRICULTURAL FIELDS IN CHAFUKUMA, SOLWEZI DISTRICT, ZAMBIA

By

JOSHUA SAKAMBUTA

A dissertation submitted to the University of Zambia in partial fulfilment of the requirements for the award of the degree of Master of Science in Environmental and Natural Resources Management.

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DECLARATION

I, Joshua Sakambuta, declare that this dissertation represents my own work, and this work has not been submitted for a degree, diploma or other qualification at this or any other university. I further declare that all the information, except for the ones whose sources have been acknowledged is original.

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CERTIFICATE OF APPROVAL

This dissertation of Joshua Sakambuta has been approved as fulfilling the requirements of partial fulfilment of the requirements for the award of a Master of Science in Environmental and Natural Resources Management by the University of Zambia.

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ABSTRACT

Kansanshi Foundation, a corporate social unit of Kansanshi Mining PLC in Solwezi has been supporting conservation agriculture (CA) among smallholder farmers in Chafukuma area since 2010 without any empirical evidence of CA benefits. This study assessed the effects of CA on soil fertility of agricultural fields in Chafukuma. Paired soil samples were collected from the fields at a depth of 0 - 20 cm. A pair consisted of one sample from a CA managed field that had been cultivated for at least five years and another from a conventional (CV) managed field that had been cultivated for over 20 years that were adjacent. The soil samples were analyzed for any statistically significant differences in available phosphorus (P), exchangeable potassium (K), total nitrogen (N), organic carbon (SOC) and pH levels. Paired sample t-test was used to analyze the soil data with the aid of SPSS Version 20. Field observations were used for recording CA practices employed on the sampled agricultural fields. Perceptions on soil fertility benefits associated with CA were investigated through semi structured interviews. Secondary data on CA were collected through the desk analysis of CA publications. The study showed evidence of CA associated improvements in soil fertility with P 4.80 mg/kg (26.09 mg/kg to 21.29 mg/kg), K 3.23 cmol/kg (11.97 cmol/kg to 8.74 cmol/kg), N 0.73 % (0.96 % to 0.23 %), SOC 1.79 % (3.31 % to 1.52 %) and pH 0.30 (5.49 to 5.19) levels in CA compared to CV managed fields. Statistical analysis showed that the levels of nutrients in CA and CV managed fields were statistically significantly different, with CA managed fields having higher values ($T_{calc.} \geq 4.520$, p value = 0.0001) than CV fields. This study found that smallholder farmers practiced minimum tillage, crop residue retention and crop rotations in their CA managed fields. These practices were either minimal or absent in CV agricultural managed fields. Farmers' perceptions were that the practice of CA improved soil fertility in their fields. The results suggest that CA statistically significantly increased the levels of SOC, N, P, K and pH among smallholder farmers' agricultural fields in Chafukuma. It was concluded that CA improved soil fertility in agricultural fields of smallholder farmers in a high rainfall area, and could be scaled up in smallholder CA systems in other high rainfall areas of Zambia provided all the important agronomic practices are utilized consistently.

DEDICATION

Dedicated to Fulanswa Sezali Sakambuta and Doris Kashala Lyonga, my late father and mother respectively. I wished you were both here to witness this achievement.

ACKNOWLEDGEMENTS

Insightful appreciation goes to my Supervisor Dr. B. B. Umar for the quality comments; my beloved wife Womba and children for their support; Kansanshi Foundation CA Officers; Mr. M. Katanga, Muyunda and D. Sasaya for their help; all the CA farmers in Chafukuma who participated in the study; Mr. J. Bwembya and Mrs. E. Sakala at Mutanda Research Station; Mr. T. Musakanya, Principal Solwezi College of Education; District Agriculture Officers and above all; God Almighty.

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ACRONYMS

AER: Agro Ecological Region

CA: Conservation Agriculture

CFU: Conservation Farming Unit

CLUSA: Co-operative League of the United States of America

COMACO: Community Market for Conservation

CSO: Central Statistical Office

DAPP: Development Aid from People to People

FAO: Food and Agricultural Organization

FAOSTAT: Food and Agriculture Organization Statistics

GDP: Gross Domestic Product

GART: Golden Valley Agricultural Trust

GRZ: Government of the Republic of Zambia

IESR: Institute of Economic and Social Research

MACO: Ministry of Agriculture and Cooperatives

NPK: Nitrogen, Phosphorous and Potassium

SCAFEP: Soil Conservation and Agro-forestry Extension Project

SPSS: Statistical Package for Social Sciences

SSA: Sub-Saharan Africa

UN: United Nations

USA: United States of America

ZNFU: Zambia National Farmers Union

CHAPTER ONE

INTRODUCTION

1.1 Background

Declining soil fertility is reported to be widespread and a major threat to food security, agro-ecosystem sustainability and livelihoods across Sub-Saharan Africa (SSA) where the majority of people directly depend on agriculture (Gruhn *et al.,* 2000; Grabowski *et al.,* 2014*).* Approximately, 65 % of Africa's population experience effects of soil degradation while about 3 % of gross domestic product (GDP) from agriculture is lost annually because of loss of nutrients from the soil (Drechsel *et al.,* 2001). To maintain total production smallholder farmers responded to the decline in soil fertility by shifting cultivation, abandoning degraded agricultural fields and converting new lands for agricultural production (Padwick, 2008). The smallholder farmers were also said to cause soil fertility decline by routinely burning crop residues, mining nutrients off fields through the removal of harvested crops and failing to incorporate appropriate and sufficient soil conservation practices in their farming systems (Somasiri, 1994).

One option increasingly advocated for redressing this soil fertility decline, enhancing agro-ecosystem sustainability and improving crop productivity and household food security among smallholder farmers in SSA is conservation agriculture (CA) (CFU, 2006; FAO, 2010; Rusinamhodzi *et al.*, 2011). The Food and Agricultural Organization (FAO) defines CA as an approach used to manage agro-ecosystems in a way that raises profits and improves food security; and enhances the resource base while sustaining or improving productivity (FAO, 2011). CA is described as an agricultural system based on the simultaneous application of its three principles namely; minimum mechanical soil disturbance, permanent soil cover with organic materials such as crop residues or cover crops and diversified crop rotations to enhance soil fertility and to supply food from a dwindling land resource (Haggblade and Tembo, 2003; Umar *et al.,* 2011; Grabowski *et al.,* 2014). CA's underlying principles of minimum soil disturbance, permanent soil cover and diversified crop rotations are increasingly recognized as essential for sustainable agriculture (Erenstein *et al*., 2012). Marongwe *et al.,* (2011) contended that CA tries to remove unsustainable parts (maximum tillage, residue removal and mono-cropping) from conservation agriculture system, thereby addressing most of the issues restricting yield increases such as soil fertility decline.

In Zambia resources were being spent on supporting CA by a number of organizations such as the Conservation Farming Unit (CFU) of the Zambia National Farmers Union (CFU, 2006), the Ministry of Agriculture (CFU, 2006), Community Market for Conservation (COMACO), the Food and Agricultural Organization (FAO) (FAO, 2006), to name but a few, to try to mitigate the problem of agro-based soil degradation. Kansanshi Foundation, a corporate social unit of the Zambia's largest Mining Company, Kansanshi Mining PLC is another such organization. It has been supporting CA among smallholder farmers in Chafukuma area in Solwezi District of North Western Zambia since 2010. According to Chomba (2004) smallholder farmers were those who cultivated land area that was less than five hectares. According to Kansashi Foundation the goals of promoting CA in the area were to increase food security, enhance soil fertility and agro-ecosystem sustainability. Kansanshi Foundation has been supporting CA in Chafukuma for over five years. Chafukuma is a good case of a high rainfall area in Zambia. Its soils are inherently of low fertility because they are highly leached of nutrients and strongly acidic due to the high rainfall received in the area (Chomba, 2004, Yerokun, 2008). Soil erosion and nutrient mining are also prevalent due to unsustainable farming practices such as the removal and burning of crop products and crop residues respectively, and accelerated mineralization of soil organic matter through tillage (Mukanda, undated). According to Kansanshi Foundation, a total number of 2, 100 smallholder farmers had been involved from the beginning of the project to date. Although a few studies had been conducted on effects of CA on soil fertility in Zambia (c.f. Umar *et al.*, 2011; Thierfelder and Wall, 2010; Muchabi *et al*., 2014), these were from the low to medium rainfall agro-ecological regions. The objective of this study therefore was to determine whether or not the practice of CA in the study area had resulted in improved soil fertility among smallholder farmers' agricultural fields.

1.2 Statement of the Problem

Previous research done in Central, Southern and Eastern provinces of Zambia on the effects of CA on soil fertility of agricultural fields managed by smallholder farmers did not find any significant effects (Thierfelder and Wall, 2010; Umar *et al*., 2011; Umar *et al*., 2013). Despite this many organizations have continued promoting CA as a strategy for improving soil fertility. This is a misallocation of scarce resources which also prevents the search for more effective solutions to the challenge of soil fertility. Also noteworthy is that the studies were from low to medium rainfall areas of Zambia. The researcher did not come across any studies on the effects of CA on soil fertility from a high rainfall area of Zambia. Chafukuma is in AER III, the high rainfall agro-ecological region. Soil analysis would provide empirical evidence on whether CA was working in mitigating the problem of low soil fertility in a high rainfall area or not.

1.3 Aim of the Study

The aim of the study was to assess the effects of CA on soil fertility among smallholder farmers' agricultural fields in Chafukuma, Solwezi.

1.4 Objectives of the Study

The objectives of the study were to;

1. Investigate the CA practices of smallholder farmers in Chafukuma.
2. Determine whether CA practices had any significant improvements on the soil fertility of the agricultural fields in Chafukuma or not.
3. Investigate farmers' and Kansanshi Foundation field officers' perceptions on CA benefits to soil fertility in Chafukuma.

1.5 Research Questions

The research questions for the study were;

1. What CA practices have the smallholder farmers in Chafukuma been using in the last five years?
2. What are the reasons for smallholder farmers' use of CA practices?
3. What are the effects of CA on selected chemical properties of soils in the agricultural fields of smallholder farmers in Chafukuma?
4. What benefits to the soil are associated with CA by farmers and Kansanshi Foundation field officers in Chafukuma?
5. How do the perceptions of farmers and Kansanshi Foundation field officers on soil fertility benefits of CA compare with the soil analysis results?

1.6 Research Hypothesis

There were significant differences in soil fertility between CA and conventional (CV) agriculture managed fields.

1.7 Significance of the Study

The study helps to raise the level of CA adoption and diffusion among farmers in Chafukuma and other high rainfall areas of Zambia by providing empirical evidence of the benefits of CA experienced by the farmers that have adopted it. This study provides an independent feedback to efforts of mitigating soil fertility decline in high rainfall regions. Thus, results could be of use to CA promoters and development actors in CA projects' designs and implementation. By showcasing what has been done in Chafukuma, the study results can be used by CA promoters as an example of what to do and also what not to do in CA promotion in high rainfall regions. The study also contributes knowledge to the highly contested subfield of conservation agriculture which is currently characterised by debates on contribution of CA to, among other issues, soil fertility.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

This chapter presents a review of the relevant literature on soil fertility and conservation agriculture in terms of soil fertility decline in SSA in general and Zambia in particular; challenges of soil fertility in high rainfall areas of Zambia; CA as an option for redressing soil fertility decline problem and assessment of benefits of CA practices to soil fertility in Zambia and gaps.

2.2 Soil Fertility Decline in SSA

Many of Africa's soils were reported to be heavily depleted of nutrients; to the extent that soil organic matter was very low; below 1.0 % or even 0.5 % in the topsoil (Liniger *et al.*, 2011). Soils on cropland in SSA were reported to be depleted by about 22 kg nitrogen (N), 2.5 kg phosphorus (P) and 15 kg potassium (K) per hectare per year (FAOSTAT, 2008); while nutrient loses due to erosion ranged from 10 kg to 45 kg of NPK per hectare per year (FAO, 2011). Above that, 25 % of the soils were said to be acidic with deficiency in phosphorus, calcium and magnesium and had high levels of aluminium (FAO, 2011). Soil fertility constraints to crop production have been recognized widely as a major obstacle to food security and agro-ecosystem sustainability in SSA (Buerker *et al.,* 2002).

2.3 Explaining Soil Fertility Decline in SSA

Declining soil fertility in SSA was reported to be as the result of human failures to understand and manage the soil (Waugh, 1995). Poor agricultural practices by smallholder farmers were identified as inducing soil fertility decline in the region (Liniger *et al.*, 2011). Many studies reported that the burning of vegetation and crop residues by smallholder farmers initially provided nutrients for the soil but once these were leached by the rain or utilized by crops there was little replacement of organic material (FAO, 2010; Liniger *et al.*, 2011). When crop was harvested there was less organic material left to be recycled (Liniger *et al.*, 2011; FAO, 2010). As materials were taken out of the soil system and not replaced, there was an increasing shortage of macro-nutrients particularly nitrogen (N), calcium (Ca), phosphorus (P) and potassium (K) (Umar *et al.,* 2011). Where this occurred, and when other nutrients were dissolved and leached from the soil by heavy rainfall, two options were possible; either the land was abandoned and new forests converted for agricultural production or proper land management was implemented to maintain yields (GRZ Provincial Forestry Action Programme, 2005). The latter was the most preferred option by CA promoters for resource poor smallholder farmers (FAO, 2010). CA is claimed to be a panacea for the problems of poor agricultural productivity and land degradation in SSA (Giller *et al*., 2009). It is actively promoted by international research and development organizations, with such strong advocacy that crucial debate is stifled (Giller *et al*., 2009).

Deforestation resulting from the extra need for farmland resulted in removal of vegetation cover from the topsoil (Trapnell and Clothier, 1996). That meant strong winds when they blew and the heavy rains, when they did occur, were no longer intercepted by the vegetation (Waugh, 1995). Rain splash loosened the topsoil and prepared it for removal by sheetwash (Folberth, 2014). Water flowing over the surface had little time to infiltrate into the soil or recharge the soil moisture store (Wolkowski, 2003). Where the water evaporated, a hard crust formed, making the surface less porous and increasing the amount of surface runoff (CFU, 2006). More topsoil was carried away where there was little vegetation because there were neither plant roots nor organic matter to bind it together (Wolkowski, 2003). Small channels or rills formed which in time, developed into large gulleys making the land unsuitable for agriculture (Folberth, 2014).

Deep ploughing is reported to have destroyed the soil structure by breaking up peds and burying organic material too deep for plant use (Wolkowski, 2003; Waugh, 1995). Ploughing loosens the top soil making it susceptible to wind and water erosion (Waugh, 1995). Ploughing up and down hill (slope) creates furrows which increased the rate of surface runoff and the process of gullying (Wolkowski, 2003). Erosion adversely affects crop productivity by reducing the availability of water, nutrients and organic matter, and as the topsoil thinned, by restricting rooting depth (Pimentel *et al.*, 1987; Folberth, 2014).

2.4 Soil Fertility Decline in Zambia

Declining soil fertility was reported to have occurred in various parts of Zambia for the same reasons as those advanced in SSA (FAO, 2006). Declining soil fertility in Zambia was reported to be as a result of land mismanagement (CFU, 2006) as well as natural causes such as erosion and leaching due to high rainfall (Yerokun, 2008). Unsustainable farming practices such as shifting cultivation, burning of crop residues, continuous mono-cropping, nutrient mining and deep ploughing accounted for soil degradation in Zambia (Cassman, 2012; Grabowski *et al.*, 2014). Yerokun (2008) noted that Zambia had fertile soils and good rainfall, yet kept losing its fertile topsoil and water to erosion owing to poor soil management. The loss of fertile topsoil to erosion resulted in gross loss of soil fertility in most fields of smallholder farmers and that was a big problem (Ng'ombe *et al.*, 2014).

2.5 Soil Fertility Challenges of High Rainfall Areas of Zambia

Soil baseline surveys of high rainfall areas of Zambia including Chafukuma showed that the soils were highly leached and strongly acidic with pH 4.2 (Yerokun, 2008; Chabala *et al*., 2014). The soils were of low nutrient reserves; low nutrient retention capacity and severe aluminium and iron toxicity and were characterised by red colour as they were highly oxidized (Yerokun, 2008). Studies reviewed indicated that heavy rain accelerated leaching and removed nutrients and organic matter at a rate faster than that at which they could be replaced by weathering of bedrock or vegetation breakdown (Waugh, 1995; Chomba, 2004; Yerokun, 2008). The leaching left the soil lacking in most major and some minor nutrients (Liniger *et al*., 2011). Owing to these conditions the soil in high rainfall (between 1000 mm and 1500 mm) areas of Zambia was generally infertile for crop production and required liming (Chomba, 2004; Lungu and Dynoodt, 2008).

2.6 Redressing Soil Fertility Decline through CA in SSA

Many publications reviewed on CA (c.f. CFU, 2006; Erenstein *et al*., 2012; FAO, 2010; Marongwe *et al.*, 2011; Ndeunga *et al*., 2005; Nyende *et al*., 2004; Rusinamhodzi *et al.*, 2011; Thierfelder and Wall, 2010; Umar *et al*., 2011; Wolkowski, 2003) suggested that CA was increasingly advocated for redressing soil fertility decline and improving crop productivity and household food security in SSA. CA is a system based on the practice of dry-season land preparation, minimum tillage; permanent soil cover with organic materials such as crop residues or cover crops (crop residue retention); and diversified nitrogen-fixing crop rotations (FAO, 2010; Rusinamhodzi *et al.*, 2011).

Benefits of CA to soil fertility reported in literature included significantly improved physical and chemical properties of soil (Wolkowski, 2003); increased soil biotic diversity (Thierfelder and Wall, 2010) and higher soil organic matter content from constant addition of crop residues (Chivenge *et al.*, 2007). Soils under CA exhibited high water infiltration rates; reduced surface runoff and consequently lowered soil erosion (Thierfelder and Wall, 2010).

CA helped to enhance the stability of soil aggregates (Marongwe, 2011). Retaining crop residues helped retain soil particles and the associated nutrients on the field (Liniger *et al.*, 2011).

2.7 CA Promotion in Zambia

CA promotion and practices in Zambia date back to the late 1980s and early 1990s (Haggblade and Tembo, 2003). In the late 1990s and early 2000s, CA practices attracted the attention of a number of donor-financial non-governmental organizations (NGOs) such as the Co-operative League of the United States of America (USA) (CLUSA), Concern Worldwide, Development Aid from People to People (DAPP), and Dunvant Zambia Limited (Tembo *et al*., 2014). CLUSA required its farmers to plant in CA basins as a pre-requisite for receiving input credit (Tembo *et al*., 2014). Dunvant Zambia Limited increased its commitment to CA in its farmer training and support programmes (Haggblade and Tembo, 2003). The Government of the Republic of Zambia (GRZ) has since the mid-1990s being promoting CA practices amongst the farming population (Haggblade and Tembo, 2003). Other major organizations that have joined in the efforts to promote CA among smallholder farmers include Conservation Farming Unit (CFU) of the Zambia National Farmers Union (ZNFU) (CFU, 2006) which has been promoting CA among farmers since 2006 (CFU, 2006); the Department of Field Services in the Ministry of Agriculture and Co-operatives (MACO); the Soil Conservation and Agro-forestry Extension Project (SCAFEP) and the Golden Valley Agricultural Trust (GART) (Kabwe *et al*., 2007; GART, 2008). GART has been promoting the Magoye Ripper Project in maize and cotton production in Southern and Eastern Provinces (Kabwe et *al*., 2007; GART, 2008). These promotion efforts were initially concentrated in the low to medium rainfall regions of the country but have increasingly also included the high rainfall areas of northern Zambia. For instance the Food and Agricultural Organization (FAO) of the United Nations in collaboration with the Ministry of Agriculture has been implementing the Conservation Agriculture Scaling Up (CASU) project from 2013 in 31 districts of Zambia including several from northern Zambia. The Community Markets for Conservation (COMACO) is involved in CA promotion in North Eastern Zambia. COMACO has being promoting the growing of legumes by providing ready market to the smallholder farmers in Northern, Eastern and Muchinga provinces of Zambia (Haggblade and Tembo, 2003). In a similar vein, Kansanshi Foundation, a corporate social unit of Zambia and Africa's largest open cast mine, Kansanshi Mining PLC has been promoting CA among smallholder farmers in Chafukuma area of Solwezi district since 2010 to help smallholder farmers; most of who cannot access adequate quantities of mineral fertilizer improve the fertility of soils on their agricultural fields (Haggblade and Tembo, 2003). The major objective of these activities was to increase knowledge and adoption of CA practices by smallholder farmers in Zambia. Despite the efforts to promote CA in the high rainfall regions of Zambia, there was no indication of any studies on the effects of CA on soil fertility from a high rainfall area of Zambia (Muchabi *et al*., 2014).

CA as promoted among smallholder farmers in Zambia was reported to involve dry-season land preparation using locally tailored minimum tillage systems (manual and traction); retention of crop residues; precise input application of seed, lime, mineral and organic fertilizers in the basins; nitrogen-fixing crop rotations; timely sowing of crops; and the management of the leguminous tree *Faidherbia albida* (Umar *et al.*, 2013; *Umar et al*., 2011). According to Umar (2012) recommended practice of manual CA in Zambia suggested digging basins with a length of 30 cm, a width of 15 cm and a depth of 20 cm. The basins were interspaced in a 70 cm x 90 cm matrix resulting in 15 850 basins per hectare. At 0.045 m^2 per basin, the total area covered by basins was 713 m^2 per hectare, representing 7 % of soil disturbance. Traction CA prescriptions involved making furrows that were 15 cm to 0 cm deep at 90 cm spacing. This was equivalent to tillage on approximately 10 % to 12 % of the land (Umar *et al.*, 2011).

2.8 Assessment of Effects of CA on Soil Fertility in other Areas and Zambia

The soil tests in the study on conservation tillage issues for NW Wisconsin reported high P; K and SOC levels in CA compared to CV managed fields (Wolkowski, 2003). The study also reported high soil pH in CA and CV managed fields respectively. A study by Thierfelder and Wall (2010) showed that CA plots in Monze, Southern Province, in general possessed higher populations of earthworms, higher total carbon and more stable aggregates. According to Kabwe and Donovan (2005) CA was seen by many as a way to develop sustainable farming systems in a region with high risk and relatively low productivity. A study on the land degradation minimizing effects of CA as promoted among smallholder Zambian farmers in medium and low rainfall areas showed high P (15.53 mg/kg) and K (0.75 cmol/kg) levels, low N (0.12 %) and organic carbon (1.19 %) levels in soils from both CA and CV tilled fields (Umar, 2012).

2.9 Scope of Assessments of CA and Gaps in Zambia

A substantial amount of work has been done in CA practices but there is still a big gap in understanding how different aspects of soil fertility are affected by these practices under different soil and agro-ecological conditions. Although CA has been widely studied, most of the studies done in Zambia have focused mainly on assessment of adoption and impact of CA on crop yields (Arslan *et al.*, 2014; Tembo *et al.*, 2014; Phiri, 2013; Kabamba *et al.*, 2009; Andersson and D'souza, 2014); farm level financial profitability (Kabwe *et al.*, 2007); adoption and area under CA (Nyanga, 2012); sustained use of CA practices (Kabwe and Donovan, 2005); adoption potential of CA practices in SSA (Ndah and Schhulor, 2014); and socio-economic effects of CA in drought mitigation (Mhambi-Musiwa, 2009). Studies on assessment of effects of CA on soil fertility have been done in low and medium rainfall areas of Zambia (Umar *et al*., 2011; Umar, 2012; Umar *et al*., 2013; Muchabi *et al.*, 2014); but there were none known from high rainfall areas. Also noteworthy is that most publications on CA have often reported on crop yields, soil water conservation, erosion control and socio-economic gains rather than on chemical soil fertility.

Related studies reviewed for the current study included a study on chemical characteristics of phosphorus in some uncultivated representative benchmark soils of Zambia where Chafukuma was covered (Yerokun, 2008); a study on integrated nutrient management soil fertility and sustainable agriculture (Gruhn *et al*., 2000); a study on land degradation-minimizing effects of CA as promoted among smallholder Zambian farmers in medium and low rainfall areas of Zambia (Umar, 2012); a study on conservation agriculture in Zambia: effects on selected soil properties and biological nitrogen fixation in soya beans in Mazabuka, Southern Province (Muchabi *et al.*, 2014) and a study on conservation tillage issues for NW Wisconsin USA on farms where machine traction was employed (Wolkowski, 2003). This study though similar in nature to the others, differed in scope and location. Soil analysis in the low and medium rainfall areas by Umar (2012) could not be generalized to a high rainfall area as climatic, edaphic and anthropogenic factors were different. However, this study was guided a great deal in approach, methodology and design by these previous studies.

The literature review has also showed that although baseline soil survey data on Chafukuma were available; existing literature on the topic in North Western Province was scanty. The review has indicated low levels of research on the research topic in North Western Province compared to other provinces such as Southern, Central and Eastern provinces. This was the knowledge gap this study sought to fill.

2.10 Soil Fertility Conceptual Framework

In the conceptual framework, (Figure 2.1) soil fertility terminologies which were introduced in the study are presented. Soil fertility decline occurs as soil loss or soil harm. Soil loss is caused by natural factors such as soil erosion and leaching as a result of high temperature and rainfall (Yerokun, 2008). Soil harm is induced by anthropogenic factors such as removal of crop products and burning of crop residues and accelerated mineralization of soil organic matter through unsustainable tillage (Liniger *et al.*, 2011). The overall effect is loss of soil fertility in the agricultural fields. CA is claimed to replenish the soil with organic matter derived from residues of crops or nutrient accumulation (e.g. nitrogen fixing), external inputs of organic matter, manure and mineral fertilizer (FAO, 2011). In the conceptual framework the broken arrows denote soil fertility improvement pathway from CA while the solid arrows denote soil fertility loss pathway from unsustainable farming, leaching and soil erosion.

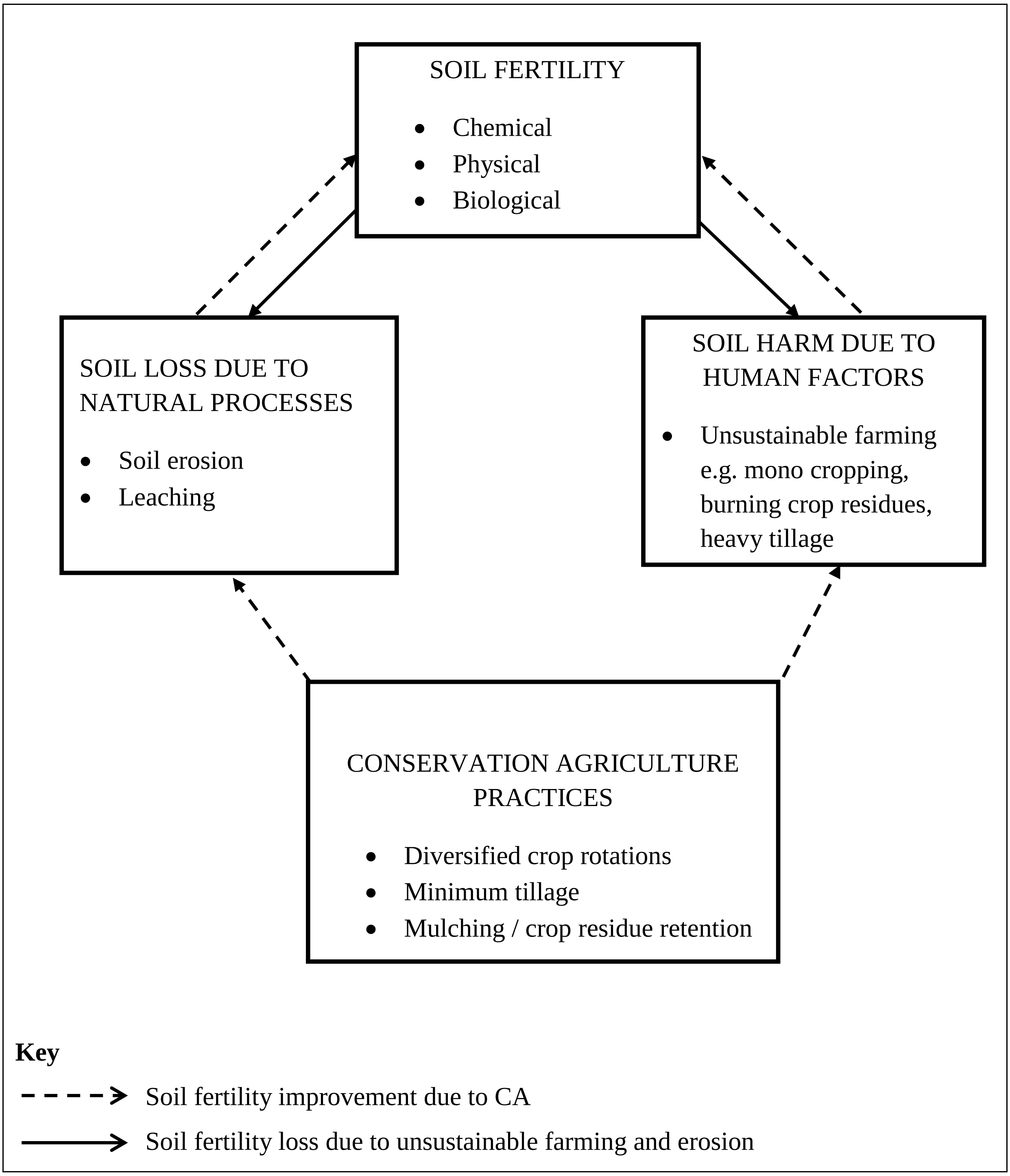

Figure 2.1 Soil Fertility Conceptual Framework

(*Adapted from the Biomass and Nutrient Cycle Model (Liniger et al., 2011*)

CHAPTER THREE

DESCRIPTION OF CHAFUKUMA AREA

3.1 Overview

This chapter describes the study area in terms of location, agro-ecological characteristics and socio-economic activities. These are detailed below under various headings.

3.2 Location

The study was under taken in Chafukuma which is located 50 km north - east of Solwezi Central Business District (CBD), on Longitude 26°, 27° E, Latitude 12°, 13° S, 1 500 m above sea level; in the North Western Province of Zambia (Figure 3.1). Chafukuma is in Agro-Ecological Region III (AER III). AER III is a high rainfall area in Zambia receiving mean annual rainfall between 1000 mm and 1500 mm (GRZ Meteorological Department, 2015). Chafukuma was chosen out of the 13 farming blocks in Solwezi because Kansanshi Foundation has been promoting CA among smallholder farmers there for over five years.

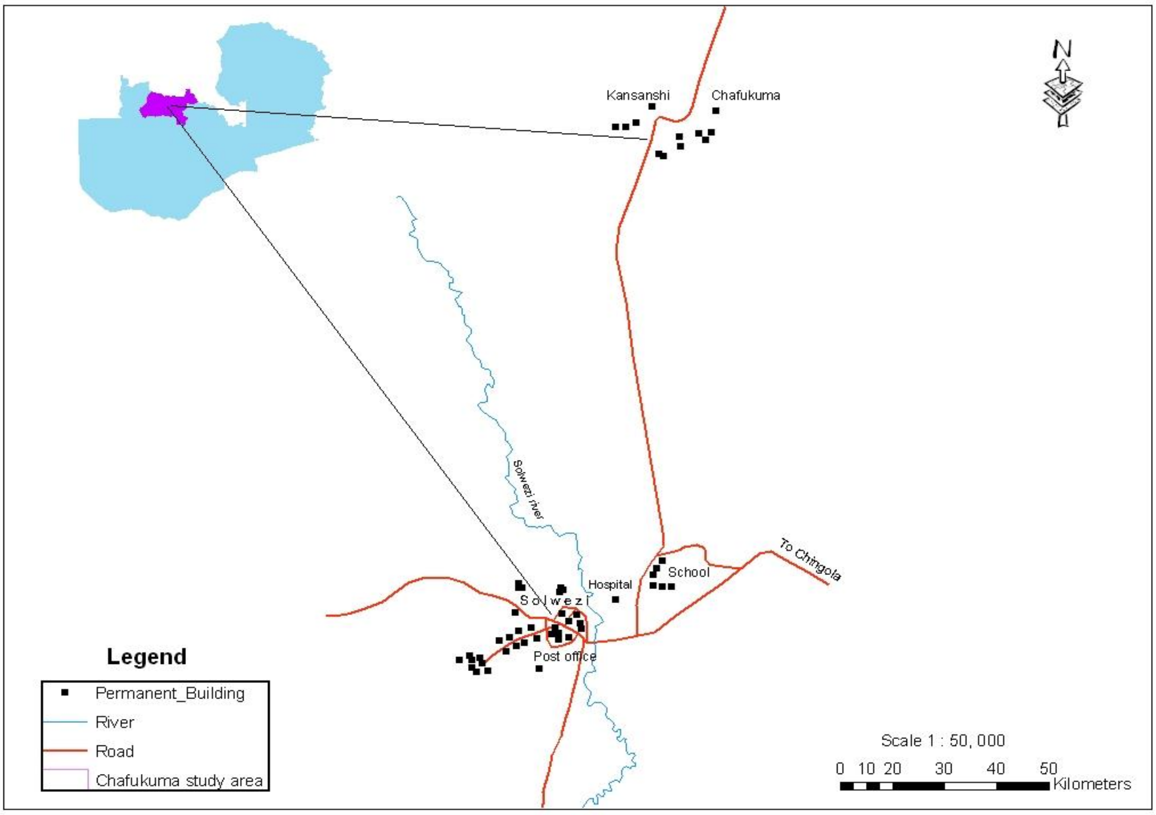

Figure 3.1 Location of Chafukuma Area

3.3 Climate

Chafukuma has three seasons namely cold- dry season which is from April to August; hot-dry season from September to November and hot-wet season from November to March. The lowest mean annual temperature is 12 ^{O}C while the highest is 20 ^{O}C (GRZ Meteorological Department, 2015). The crop growing period is between 120 and 150 days (Yerokun, 2008).

3.4 Geology and Soils

Much of the study area is part of the Central African Plateau underlain by a Precambrian Basement Complex composed predominantly of acidic rocks (Yerokun, 2008). Although there were subsequent depositions of basic sedimentary material, these have largely been subjected to extensive leaching, resulting into acid soils (Yerokun, 2008). Chafukuma has the Oxisol red clays type of soils (Soil Survey Research Branch, 1991; Soil Survey Division Staff, 1993) which are highly leached; strongly acidic (pH 4.2) with low nutrient reserves; low nutrient retention capacity and severe aluminium and iron toxicity (Yerokun, 2008). Widespread soil acidity is ascribed to the soils having been formed from acidic Precambrian Basement Complex parent material (Yerokun, 2008). Heavy rain accelerated leaching which left the soil lacking in most major and some micro mineral nutrients (Waugh, 1995). Owing to these conditions the soil was generally infertile for crop production and requires liming (Chomba, 2004). The soils are well drained due to the area having slopes of ≥ 2 % (Magai *et al*., 1983). This accounts for the high erosion experienced in the study area.

3.5 Vegetation

The predominant type of vegetation in the area is woodlands dominated by Brachystegia species such as *Brachystegia spiciformis L*, *Brachystegia boehmii L, Burkea africanaa L, Parinari curatellifolia L, Uapaca kirkiana L, Afzelia quanzensis L, Pericopsis angolensis L, Pterocarpus angolensis L*, to name but a few (Trapnell and Clothier, 1996; Storrs, 1979). These species favour the Oxisol, Ultisol and Vertisol type of soils and medium to high rainfall conditions (Storrs, 1979).

3.6 Population

Chafukuma is in Kapijimpanga Ward, which has 2, 939 households, and a population of 14, 385 people, 50.30 % (7, 213) males and 49.70 % (7, 172) females (CSO, 2010). The total provincial population of people in North Western was 727, 044 out of a total national population of 13, 092,666 (CSO, 2010). Out of this population, 77.4 % (563, 061) were in rural areas and 22.6 % (163, 983) were in urban areas. At district level, Solwezi District had the largest percentage of the total provincial population with 35.0 % (254,470). The total number of households in North Western Province as captured during the 2010 Census of Population and Housing was 130, 803. Male headed households made up 76.3 % (99,754) of the total number of households, while female headed households made up 23.7 % (31,049). In 2010, the population density for North Western Province was 5.8 persons per square kilometre. The population density increased from 4.6 persons per square kilometre in 2000 to 5.8 persons per square kilometre in 2010, representing an increase in density of 1.2 persons per square kilometre. Solwezi District has a population density of 8.4 persons per square kilometre (CSO, 2010). The 2016 projected human population for Solwezi district is 299,725; North Western Province 856, 286 and Zambia 15, 933,883 (CSO, 2013).

3.7 Economic Activities

The two major economic activities in the area are agriculture and mining. The residents practice shifting cultivation. The major crops grown are maize (*Zea mays L*), groundnuts (*Arachis hypogaea L*), sorghum (*Sorghum vulgare L*), cassava (*Maniholt esculenta L*), common beans (*Phaseolus vulgaris L*), finger millet (*Elusine corocana L*), bulrush millet (*Pennisetum typoides L*) and sugarcane (*Saccharum spp.*). The residents also sell beans, sugar canes and maize. Livestock and poultry rearing in the area are on a very small scale. Chafukuma is the home for the giant open pit mine called Kansanshi Mine where some of the locals are employed in some low skill positions as machine operators, cleaners, spotters, drivers, and so on. Table 3.1 presents a summary of some selected characteristics of the study area.

Table 3.1 Agro-ecological Characteristics of Study Area

Study Area	Location	Mean Annual Rainfall (mm)	Mean Annual Temp. (^{o}C)	Altitude (m.a.s.l)	Soil Types	Vegetation	Major Economic Activities	Growing season in days
Chafukuma	Solwezi	1400	20	1500	Oxisol (Red clays)	Woodlands (Brachystegia)	Agriculture Mining	120 – 150

(*Source: Adapted from GRZ Met. Dept., 2015; Yerokun, 2008)*

CHAPTER FOUR

METHODOLOGY

4.1 Overview

This chapter reports on the research design, sources of data, sampling and data collection methods employed in the study. These are detailed below under various headings.

4.2 Research Design and Approach

In this study a descriptive comparison group post- test- only comparative descriptive research design, also referred to as causal comparative descriptive research (Kombo and Tromp, 2006), was employed. Descriptive comparison research is a type of research which attempts to identify a causative relationship between an independent variable and dependent variable (Kombo and Tromp, 2006). However, this relationship is more suggestive than proven as the researcher does not have complete control over the independent variable (Azalia, 1999). In carrying out analysis based on this design, the researcher compares two selected groups on the dependent variable (Kombo and Tromp, 2006). This research design introduces a comparison group which does not receive the independent variable but is subject to the same post-test as the experimental group (Azalia, 1999). The experimental or treatment group is a group receiving a specified intervention (Kerlinger, 1969). A group used for the purposes of comparison is usually referred to as a comparison group in descriptive design and a control group in an explanatory design (Azalia, 1999).

In this study, the chemical soil fertility of two groups; namely the CA managed fields that had been cultivated for five years and the adjacent CV agriculture managed fields that had been cultivated for over 20 years were compared and the magnitudes of change presented in both percentages and ranges. The CA managed fields were the experimental group while the CV agriculture managed fields were the comparison group. CV agriculture managed fields are those tilled using conventional tillage methods such as ridging, ploughing or flat culture which involve complete soil inversion using a hand hoe, mould board plough or tractor (Umar, 2012). Soils were only collected from the pot holes in CA managed fields and tilled areas in CV managed fields that were adjacent to each other. This was in order to minimize the effects of natural soil variation in fields located far away from one another. The advantage of this design is that it may control for rival hypotheses and use a second group as a comparison (not a control). Also while a control group is always randomly assigned, a comparison group is not. Descriptive studies are not only restricted to fact findings, but may often result in the formulation of important principles of knowledge and solution to significant problems (Kerlinger, 1969). They involve measurement, classification, analysis, comparison and interpretation of data. For this reason they are positivistic quantitative (scientific) in nature (Kerlinger, 1969). The study approach was a survey. A survey study is an attempt to obtain data from members of a population (or a sample) to determine the current status of that population with respect to one or more variables (Azalia, 1999). Surveys are used in descriptive comparative research designs to collect primary data (Azalia, 1999).

4.3 Study Population

The study population was all the 180 CA practicing smallholder farmers in Chafukuma. The study targeted smallholder farmers in Chafukuma for they had been involved in CA with Kansanshi Foundation for a long time (five years).

4.4 Sample Size and Sampling

The sample size was 34 CA managed fields of smallholder farmers who were involved in CA with Kansanshi Foundation in the area since 2010. The sample size of 34 CA managed fields was arrived at using a *priori* power analysis using the software GPower 3.1.9 (Erdfelder *et al.*, 1996). The sample size of 34 provided statistical power of 0.81 for detecting moderate effect size at the (two tailed) 0.05 level of significance (Erdfelder *et al.*, 1996). Power analysis is an important aspect of experimental design (Cohen, 1988). It is a method that allows a researcher to determine the sample size required to detect an effect of a given size with a given degree of confidence (Everitt, 2002; Aberson, 2010). In order to do a power analysis, the researcher should specify an effect size (Sellke *et al*., 2001). In inferential statistics such as t-test, an effect size is a quantified measure of the strength of a phenomenon (Everitt, 2002; Cohen, 1988). It is the size of the difference between the researcher's null hypothesis and the alternative hypothesis (Frost, 2014). The advantage of this method is that it makes use of the sample mean to estimate the population mean to arrive at a reliable estimate of the population (sample size) and also uses *p* values (Orodho, 2003). In technical terms a *p* value is the probability of obtaining an effect at least as extreme as the one in the sample data, assuming the truth of the null hypothesis (Sellke *et al*., 2001; Cohen, 1988).

In the field 34 CA practicing smallholder farmers were sampled by simple random probability sampling. These were the farmers who were interviewed and from whose fields soil samples were taken for analysis. A list of all the smallholder farmers who practiced CA with Kansanshi Foundation since 2010 was obtained from Kansanshi Foundation Institute in Solwezi; and was used as sampling frame. The sampling was done by lottery as follows: the names of each of the 180 smallholder farmers who practiced CA in the study area were written on small pieces of paper. The papers were then folded thoroughly and placed in a box. One paper was drawn from the box at a time and the name recorded without replacement to avoid the risk of sampling the same farmer twice. Drawing of papers in this way continued until 34 farmers were sampled. This sampling method provided an equal chance to each member in the population to belong to the sample without bias. The CV agricultural managed fields were selected purposively on the basis of them being close (approximately 15.4 m) to the CA managed fields.

4.5 Data Collection Methods

Both primary and secondary data were collected using several data collection methods as detailed below.

4.6 Soil Sampling

Soil samples on the 34 CA and CV managed agricultural fields in Chafukuma were collected using traversing method of soil sampling (Soil Survey Division Staff, 1993). In a traversing method of soil sampling four corners of the field are determined and sampling is done diagonally (Soil Survey Division Staff, 1993). Traversing line transects were set up using ranging rods and measuring tape across each of the sampled field. Ten soil sub-samples from different locations of the sampled field were taken at 10 m interval (determined by measuring tape) starting with a randomly selected location across the traverse. Systematic sampling was preferred to other methods as it was simple and quick (Adds *et al*., 2001). Soil samples were taken from the surface horizons at 0 cm to 20 cm depth from the pot holes in CA managed fields and tilled areas in CV agriculture managed fields using soil auger. The 0 cm to 20 cm depth was preferred to other depths because it was the upper layer where biological activity and humus content were at their maximum (Waugh, 1995). It was also the zone that was most affected by the leaching of soluble materials and by the downward movement, or eluviations, of clay particles (Waugh, 1995). Soil auger was a suitable tool for soil sampling as it allowed a core of soil to be extracted from a fixed depth. Pot holes were preferred to untilled spaces between pot holes in the study because it was in the pot holes where inputs were placed. It was in the pot holes where CA actually happened. The ten soil samples which were collected from different locations of a field were thoroughly mixed and a composite sample taken (Migwi *et al.*, 2006). In total, 34 paired composite soil samples were collected. A pair was made up of one composite sample from a CA managed field and another from a CV agriculture managed field. Soils were only collected from fields on which CA had been practiced for at least five years that were adjacent to CV managed fields that had been cultivated for over 20 years. This was in order to minimize the effects of natural soil variation in fields located far away from one another. The CA and CV managed fields forming pairs were 15.4 m apart on average. Soil composites were preferred to a single sample in the study as they were representative of the soil in each field. The soil samples were air-dried and finely ground and sieved through a 2 mm (2000 µm) sieve and stored in polythene bags. Soil collection from the field was done in the first week of April, 2016; a transition period from wet to dry season when the soil in the fields was still soft.

4.7 Field Observations

Field observations were conducted on tillage practices, crop residue retention and crops planted under CA and CV tillage systems. This information was also captured from the two study visits to farmers' field days.

4.8 Household and Key Informants Interviews

Data on perceptions of farmers were collected through interviews. A total number of 37 interviews were conducted; 34 semi structured interviews with the farmers, two with purposively selected Kansanshi Foundation field officers and one with a district agriculture officer. The 34 CA practicing smallholder farmers were individually interviewed in their local languages (*Kaonde, Luvale and Lunda*) and their responses were recorded. The kinds of questions which were asked during the interview were open and closed ended (Appendix A). Key informant interviews were employed to get more information on CA from the promoters and the public agriculture agency (Appendix B). The data from the interviews helped to complement the laboratory soil analysis results. Interviews with farmers and key informants were conducted between 27th December 2015 and 6th February, 2016.

4.9 Desk Analysis

Secondary data were collected through a desk study of publications on soil fertility and CA of peer reviewed journals, textbooks and internet databases between March 2015 and April, 2016. The desk study involved review of research results on CA published by Thierfelder and

Wall (2010); Wolkowski (2003); Liniger *et al.*, (2011); Umar, (2011; 2012; 2013); Langmead (2002; 2004); Haggblade and Tembo (2003); Rusinamhodzi *et al.*, *(*2011); Erenstein *et al*., (2012); Ndeunga *et al*., (2005); Nyende *et al*., (2004); Marongwe *et al*., (2011) to name but a few. Focus was on tillage systems comparisons, cover crops, crop yields and soil fertility. This review was conducted in order to compare and contrast the laboratory soil tests results with those reported by similar studies on the topic. Other studies reviewed included publication on chemical characteristics of phosphorus in some uncultivated representative benchmark soils of Zambia (Yerokun, 2008) and Ministry of Agriculture and Cooperatives (MACO).

4.10 Data Analysis

The soil samples were analyzed for soil organic carbon (SOC) (Walkley and Black, 1934), soil reaction or pH (Mclean, 1982), total nitrogen (Bremner, 1965), exchangeable potassium (Chapman, 1965) and plant available phosphorus (Bray and Kurtz, 1945). Paired sample T-Test was used to analyze the soil data at a probability level of $p \leq 0.05$ using Statistical Package for Social Sciences (SPSS) version 20 software (SPSS Inc, 2010). The quantitative data from the farmer interview results were analyzed using simple descriptive statistics such as the mean and standard deviation using the same software. The qualitative data from key informant interviews and farmer interviews were analyzed for common themes. Responses belonging to one theme were grouped together and their frequency of occurrences noted and reported as percentages. This gave an indication of how prevalent particular views were among the respondents. These methods are briefly described in the following subsections.

4.10.1 Soil Organic Carbon

SOC was analyzed by Walkley and Black (1934). The oxidizable organic matter in a soil sample was oxidized by $Cr_2O_7^-$ prepared in concentrated H_2SO_4 (96 %) (two volumes of acid and one volume of 1 N $K_2Cr_2O_7$) solution. Excess $Cr_2O_7^-$ was determined by titration with standard $FeSO_4$ solution and SOC was calculated from the amount of $Cr_2O_7^-$ reduced by the organic matter in the sample. A reagent blank using the above outlined procedure was run without soil. The blank was used to standardize the Fe^{2+} solution. This was done to correct the values for moisture content. The Oxidizable Organic Carbon and Organic Carbon were calculated using the expressions below. The results are presented in the results section and appendix B.

$$\% \text{ easily Oxidizable Organic Carbon } (\% C) = \frac{(B-S) X \text{ Mof } Fe2+X\ 12\ X\ 100}{\text{g of soil } X\ 4000} \quad \text{[Equation 1]}$$

$$\% \text{ Organic Matter} = \frac{\% \text{ total C X 1.72}}{0.58} \quad \text{[Equation 2]}$$

where: B= mL of Fe^{2+} solution used to titrate blank;

S= mL of Fe^{2+} solution used to titrate sample

12/4000 = milliequivalent weight of C in g

4.10.2 Soil Reaction (pH $CaCl_2$)

Soil pH was measured in 0.01 M $CaCl_2$ using a soil to solution ratio of 1: 2.5. The pH values were determined by a pH electrode meter. Results are presented in results section and appendix B.

4.10.3 Total Nitrogen

Total nitrogen was determined by Macro Kjeldahl procedure (Bremner, 1965). The soil sample was decomposed (at about 390 ^{o}C) using strong sulphuric acid (H_2SO_4), an inorganic salt (K_2SO_4) and a catalyst (copper). The liberated NH_3 was collected in a trapping solution of an accurately measured amount of standard acid (H_2SO_4) (15 ml) solution in water (70 ml). The amount of ammonia distilled off from the digestive solution was then determined by titration of excess acid (H_2SO_4) with a standard NaOH (50 %) solution using Methyl Red indicator, and hence the amount of nitrogen (%) in the sample calculated by the equation below. The results of this procedure are presented in the Appendix B.

$$\% N = \frac{[\text{mL standard acid X N of acid}) - (\text{mL blank X N of base})] - (\text{mL standard base X N of base}) X\ 1.4007}{\text{Weight of sample in grams}}$$

[Equation 3]

Note: In the equations above, N represents normality; mL blank refers to the millilitres of base needed to back titrate a reagent blank if standard acid is the receiving solution.

4.10.4 Exchangeable potassium

Exchangeable K was determined by extraction of soil sample with neutral ammonium acetate (1M NH_4OAc) solution (pH 7) (Chapman, 1965). The suspension was then centrifuged at 6 000 rpm for five minutes. Potassium was then determined in the supernatant solution from the centrifuge by Atomic Absorption Spectrometry. The exchangeable K was calculated using the expression below. The results of this procedure are presented in the Appendix B.

Exch. K= $\frac{(a-b)*20*mcf}{10*39.10*s}$ [$cmol_c$/kgsoilDW] [Equation 4]

where: a=mg/l K in extraction solution; b= ditto in blanks; s= air-dry sample weight in gram; mcf = moisture correction factor, 20= mL of NH_4OAc used in extraction

4.10.5 Plant Available phosphorus

Plant available phosphorus was determined by extraction using a mixture of 0.03 N NH_4F and 0.025 N HCl solutions for 40 seconds to five minutes at an extraction ratio of 1:7 to 1:5 (Bray and Kurtz, 1945). The P fraction extracted is called Bray P1 and the reference to the method is Bray and Kurtz, 1945. The results of this procedure are presented in appendix B.

4.11 Ethical Considerations

Verbal informed consent was sought from all the farmers whose fields were subjected to the study and Kansanshi Foundation after the purpose of the study had been clearly explained to them. The information availed was used for the purpose of the study; and the farmers and Kansanshi Foundation officers were kept anonymous when the results were presented. The farmers and Kansanshi Foundation field officers were briefed about the findings after the study for their reactions. Field photographs were taken with permission.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Overview

This chapter of the dissertation presents and discusses the results of the study. The results are discussed in context by comparing them to other studies on similar topics done elsewhere by researchers.

5.2 Demographic Characteristics of CA Smallholder Farmers, Chafukuma

The sample consisted of both men and women CA practicing smallholder farmers most of whom were married and whose mean age was 52.7 years. Agriculture was their main source of livelihood. Table 5.1 presents the demographic characteristics of these farmers.

Table 5.1 Demographic Characteristics of the Smallholder Farmers in Chafukuma

Variable	**Value**	**Frequency (n =34)**	**(% Resp.)**
Gender	Men	23	67.7
	Women	11	32.4
Mean age (years)	52.7		
Marital status	Married	32	94.1
	Single	2	5.9
Educational level	No Formal educ.	3	8.8
	Primary	14	41.2
	Secondary	17	50.0
	Tertiary	0	0
Major economic activity	Farming	34	100
Mean No. of years of practicing CA	5	34	100
CA practicing Field over 5 years	Same	34	100
Estimated average area of land cultivated (ha)	1.0	34	100
Ownership of CV fields	Own	34	100
Approx. distance between CA and CV fields (m)	15.4	34	100

5.3 Soil Nutrient Levels from CA and CV Agriculture Fields

The study showed evidence of CA associated improvements in soil fertility in Chafukuma. These results are summarized and presented in Table 5.2 while the detailed results are in Appendix C.

Table 5.2 Soil Nutrient Levels and Paired Sample T-Test Results from CA and CV Fields in Chafukuma

Soil Parameter	CA Field Mean (n=34)	Status	CV Field Mean (n=34)	Status	Paired T-Test (95% CI) Results	Conclusion
Total N (%)	0.96 (*0.2*)	High	0.23 *(0.2)*	Low	t =19.878 *p* = 0.0001	Significantly different
SOC (%)	3.31 (*0.3*)	High	1.52 *(0.3)*	Low	t= 28.59 *p* = 0.0001	Significantly different
P (mg kg^{-1})	26.09 *(5.0)*	High	21.29 *(3. 9)*	High	t = 4. 720 *p* = 0.0001	Significantly different
K (cmol kg^{-1})	11.97 *(3.0)*	High	8. 74 *(2.6)*	High	t= 8. 787 *p* = 0.0001	Significantly different
pH (1-14)	5. 49 *(0.2)*	Slightly acidic	5. 19 *(0.2)*	Slightly acidic	t = 4.520 *p* = 0.0001	Significantly Different

Note: Statuses guided by average figures for the Tropics (Landon, 1984; Aune, 1997). The values in parentheses denote standard deviation

Table 5.3 Soil Fertility Improvement in CA Compared to CV Fields

Parameter	CA Field	CV Field	Improvement
Total N (%)	0.96	0.23	0.73
SOC (%)	3.31	1.52	1.79
P (mg kg^{-1})	26.09	21.29	4.80
K (cmol kg^{-1})	11.97	8. 74	3.25
pH (1-14)	5. 49	5. 19	0.30

5.3 Effect of CA Practice on Selected Soil Chemical Properties in Chafukuma

Field empirical evidence from soil analysis show high levels of total soil nitrogen (N), soil organic carbon (SOC), plant available phosphorus (P) and exchangeable potassium (K) in CA compared to CV managed fields in Chafukuma (Table 5.2 and Table 5.3).

5.3.1 Soil Reaction (pH)

Statistical differences in soil reaction between CA and CV agriculture managed fields at $P \leq 0.05$ level of significance were observed (Table 5.2). The soils from CA managed fields had a higher pH (5.49) than that from CV agriculture managed fields 0.30 (5.49 to 5.19) (Table 5.3). The soil analysis results show that all the soils were slightly acidic. This pH was highly satisfactory for the normal growth of most crops grown in the tropics (Landon, 1984; Aune, 1997; Soils Research Team, 2016). However, the pH was slightly higher 0.30 (5.49 to 5.19) in CA than CV agricultural managed fields despite lime (1000 kg per ha) having been applied to both types of fields. This increase in pH (0.30) in CA managed fields could not be attributed to liming only but also the buffering effect of accumulated soil organic matter under CA. Similar findings were reported on CA managed fields in low and medium rainfall areas of Zambia (Umar *et al*., 2011; Duiker and Beegle, 2006).

5.3.2 Soil Organic Carbon (SOC) and Total Soil Nitrogen (N)

There were statistical significant differences in the SOC contents between CA and CV agricultural managed fields (Table 5.2). SOC under CA managed fields was higher than in CV managed fields 1.79 % (3.31 % to 1.52 %) (Table 5.3). All the soils in CA managed fields had SOC amounts above the critical limit of 1.5 % for crop productivity (Fairhurst, 2012; Soil Research Team, 2016; Aune *and* Lal, 1997) which could be due to this increase. The differences between SOC contents in soils from CA and CV agriculture managed fields were significant at five years of CA practice. While appreciating debates suggesting longer periods of over five years for sufficient SOC to accumulate in CA managed fields (Muchabi *et al*., 2014; Umar *et al*., 2011); this study has shown that even at the period of five years sufficient accumulation of SOC (1.79 %) can still be achieved provided farmers are closely supervised. This is contrary to the study by Umar *et al.,* (2011) which showed that soils from five year old CA trials in Eastern, Southern and Central provinces of Zambia did not accumulate significantly higher amounts of SOC compared to soils from CV agriculture managed fields. Also previous research in low rainfall area did not find significant results after four years of CA practice either (Muchabi *et al*., 2014). The low levels of SOC in CV agriculture managed fields could be attributed to the burning and removal of crop residues from the fields (Umar *et al*., 2011) while the high levels of SOC in CA managed fields could be attributed to crop residue retention (Marongwe, 2011; Chivenge *et al*., 2007; Dolan *et al*., 2006; Muchabi *et al*., 2014). Incorporation of crop residues in CV agriculture managed fields hastens decomposition and mineralization of soil organic matter leading to carbon loss, while the practice of CA promotes organic carbon stabilization (Umar *et al*., 2011; Muchabi *et al*., 2014).

Nitrogen is essential in plant nutrition and is required in large amounts. Its levels in the soil provide a good indication of soil fertility (Govaerts *et al*., 2007). In this study statistically significant differences in total N were observed in soils in CA and CV agriculture managed fields (Table 5.2). Soils under CA had more total nitrogen than those under CV tillage 0.73 % (0.96 % to 0.23 %) (Table 5.3). At least all samples were above the critical levels (0.25 %) for crop production (Soils Research Team, 2016; Aune and Lal, 1997) which could be attributed to this increase. The levels of N were higher than the optimal amount (0.25 %) needed for plant growth (Tisdale, Nelson, & Beaton, 1985). Addition of crop residues and crop rotations, a characteristic of CA systems, are associated with increased total soil N (Govaerts *et al*., 2007). The results from this study are contrary to the report by Umar *et al*. (2011) who did not find any significant differences in the amounts of total N between CA and CV agriculture managed fields after five years of CA practice; but consistent with the report by Muchabi *et al*., (2014) who found significant differences in the amounts between CA and CV agriculture managed fields.

5.3.3 Available Plant Phosphorus (P) and Exchangeable Potassium (K)

Statistical differences were observed in the levels of available plant phosphorus (P) in soil samples from the CA and CV agriculture managed fields (Table 5.2). Soils from CA managed fields had higher available plant P than those from CV agriculture managed fields 4.80 mg/kg (26.09 mg/kg to 21.29 mg/kg) (Table 5.3). However, high levels of P were also observed in CV agriculture managed fields P (21.29 mg/kg) which could be attributed to other factors besides the agricultural practice. Being the second most limiting single nutrient after nitrogen, available phosphorus (P) deficiency is very common in acidic regions such as the high rainfall areas of Zambia (Soil Fertility Team, 2016). In this study the values for the fields indicate adequate to very rich levels of phosphorus for crop production (Soil Fertility Team, 2016; Aune and Lal, 1997). The results show that available P was 4.80 mg/kg more in soils from CA than CV agriculture managed fields. The results of this study show statistical significant differences for available phosphorus and potassium. This result was consistent with the report by Muchabi *et al*., (2014) who found similar observations in a low rainfall area.

5.3.4 Paired Sample T-Test Analysis Results

The p value of 0.0001 was obtained for all the parameters investigated in this study (Table 5.2). Paired sample T-Test analysis shows that the nutrient levels in CA and CV agriculture managed fields despite were statistically significantly different at $p \leq 0.05$ level of significance; with CA managed fields having higher values than the CV agriculture managed fields (Table 5.2). The p value of 0.0001 obtained in this study at $p \leq 0.05$ level of significance suggests that the differences in the analyzed chemical soil fertility parameters could not have been due to chance or effect within the sample data due to random sampling error but to the CA practice.

The plant available P, total N, SOC, exchangeable K and pH values observed in this study were practically significant for crop production (Aune and Lal, 1997). The study found high levels of N 0.73 % (0.96 % to 0.23 %), SOC 1.79 % (3.31 % to 1.52 %), P 4.80 mg/kg (26.09 mg/kg to 21.29 mg/kg), K 3.23 cmol/kg (11.97 cmol/kg to 8.74 cmol/kg) and pH 0.30 (5.49 to 5.19) (Table 5.3) in CA compared to CV managed fields in a high rainfall area. This could be probably because all the farmers whose fields were studied consistently practiced CA on the same fields for at least five years; adhered to the principles of CA practice of minimum tillage, crop residues retention, cereal-legumes crop rotations, timeliness in land preparation and were constantly being supervised and monitored by Kansanshi Foundation field officers. On the other hand these agronomic practices and supervision were either minimal or absent for CV agriculture managed fields.

5.4 Evidence from Farmer and Key informants Interviews and Field Observations

The study found evidence of the use of CA soil management practices by most farmers on the claimed CA managed fields.

5.4.1 CA Practices of Smallholder Farmers in Chafukuma

All the farmers interviewed practiced manual CA in all of their CA managed fields. Field observations found that all (100 %) the farmers whose fields were studied practiced minimum tillage, crop residue retention and crop rotations in their CA managed fields. They also applied agricultural lime (1000 kg per ha) in their fields and did not burn crop residues. They claimed to have been practicing this for five years in the same fields. These CA practices found by this study conformed very well to those recommended in low and medium rainfall areas of Zambia (Thierfelder and Wall, 2010; Umar *et al*., 2011; CFU, 2009). CA as promoted among smallholder farmers in Zambia involved dry-season land preparation using locally tailored minimum tillage systems (manual and traction); retention of crop residues; precise application of inputs such as seeds, lime, mineral and organic fertilizers; nitrogen fixing crop rotations; timely sowing of seeds; and the management of the leguminous tree *Faidherbia albida* (Umar *et al*., 2013; Umar *et al*., 2011; CFU, 2009). This study found that all the farmers practiced and generally exhibited good agronomic knowledge of CA technologies. This could be attributed to effective extension support in CA from Kansanshi Foundation.

5.4.1.1 Tillage Type

All the smallholder farmers interviewed (100 %) in Chafukuma practiced manual CA on their CA managed fields. This study's results suggest that the farmers were actually making pot holes and not the prescribed basins. The pot holes were circular and smaller than the basins. The pot holes were 30 cm wide and 20 cm deep. They were interspaced in a 60 cm x 75 cm matrix resulting in 22222 pot holes per hectare. Using the formula; area of a circle = πr^2, where $\pi = 3.142$, r = 15 cm, the area of one pot hole was 0.07 m^2. At 0.07 m^2 per pot hole, the total area covered by pot holes was 1 555.5 m^2 per hectare, representing 16 % of minimum soil disturbance which was outside the threshold for definition of minimum tillage, which stipulates less than or equal to 10 % of the area of land is tilled (Umar *et al.,* 2011). This result was inconsistent with the observation by Umar *et al*., (2012) in low and medium rainfall areas in Zambia who found 9.5 % of soil disturbance in manual CA and between 9 % and 11 % for traction CA in low and medium rainfall areas. This according to Umar *et al*., (2012) suggested a significant reduction in soil disturbance. The 16 % minimum soil tillage found in this study could be attributed to the many pot holes in the CA managed fields. The use of pot holes in CA managed fields under minimum tillage found in this study was contrary to the use of basins reported in most publications on CA in low and medium rainfall areas (Nyanga, 2012; Umar *et al*., 2011; Therfielder and Wall, 2010). This could be because in low and medium rainfall areas focus is on moisture conservation and basins are ideal for that purpose while in high rainfall areas it is on conservation of inputs placed in the soil (Therfielder and Wall, 2010). The CA practice of minimum tillage found in this study was consistent with that reported in most publications on CA in Zambia (Umar *et al*., 2011; CFU, 2006; FAO, 2010, Muchabi *et al*., 2014).

5.4.1.2 Crop Residue Retention

When asked if they retained crop residues in the fields all the farmers (100 %) claimed that they did. But field observations revealed that of all the fields; 88.2 % had excellent residue cover while 11.8 % had very little. Field observations also revealed that crop residues were retained in disproportionate amounts after harvest by the farmers whose fields were sampled. The disproportionate amounts of crop residues retained after harvest observed in CA managed fields could be because different types of crops produce different amounts of biomass and consequently different amounts of residues. The farmers practiced crop residue retention in which maize stalks, grass or weeds were retained on the fields which was evident in the fields. All the farmers (100 %) whose fields were sampled did not burn the crop residues. Figure 5.1 shows a CA managed field of one of the interviewed farmers in Chafukuma on which crop residue retention was practiced. Crop residues retention is beneficial as it results in higher surface soil organic matter content and higher infiltration rates, reducing surface runoff and soil erosion (Thierfelder and Wall, 2010; Wolkowski, 2003). There was also evidence of crop residue retention and no burning being practiced on some CV agriculture managed fields.

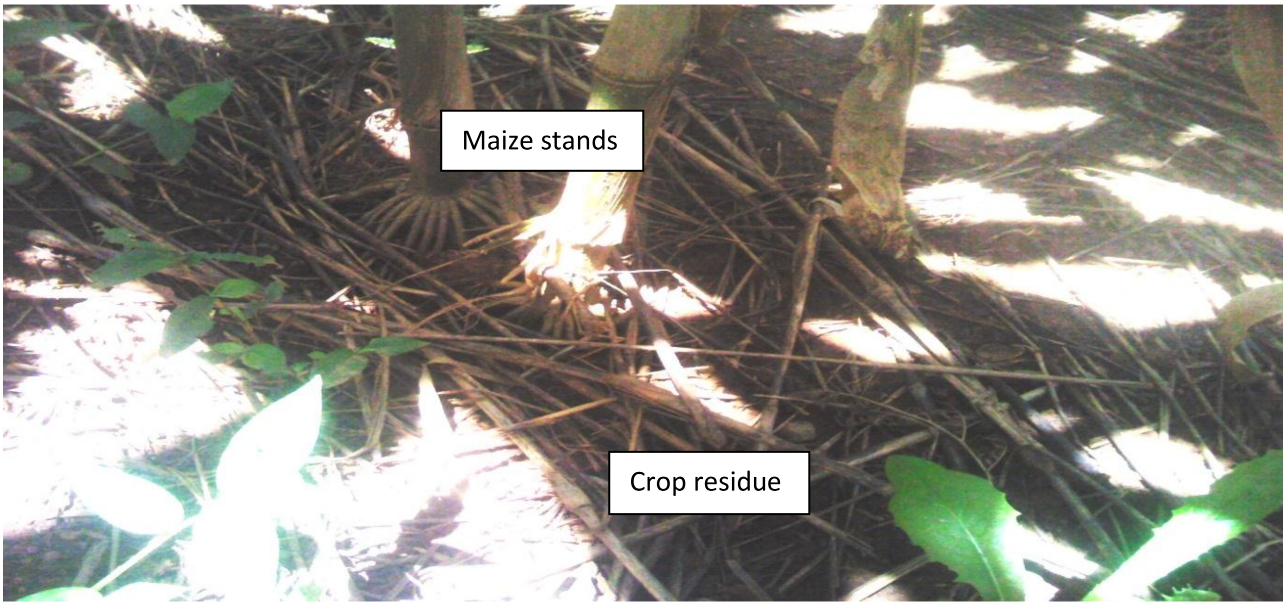

Figure 5.1 Crop Residue Retention in CA Maize Field in Chafukuma

5.4.1.3 Crop Rotation

When asked to mention the crops they grew in the last two years in their CA managed fields; farmers gave varying responses, presented in Table 5.4. When asked to give reasons for growing a particular named crop in the fields; 100 % said they grew maize and common beans for consumption and sale, maize being a staple food crop. According to the farmers soya beans was grown for inclusion in crop rotation with maize to improve soil fertility and also for sale. There was sufficient evidence from field observations of all the farmers (100 %) practicing crop rotation where maize (cereal) was grown in rotation with either common beans or soya beans (legumes) in the fields that were studied. Figure *5.2* shows a CA managed field of one of the interviewed farmers in Chafukuma on which crop rotation was practiced. However, maize was the major crop which was grown by all the farmers. The benefits of crop rotation according to the farmers were that it helped to replenish soil nutrients and break the cycle of pests and diseases in their fields. Although crop rotations were being practiced by the farmers in their CA managed fields, these were not diversified. Mostly it was common beans and soya beans that were being grown in rotation with maize. This could be attributed to the other legumes such as groundnuts being unsuitable for production using manual CA tillage systems. Most of the CV agriculture managed fields (over 60 %) that were observed were maize fields which were indicative of dominance of maize. There was also evidence of crop rotation being practiced on some CV agriculture managed fields.

Table 5.4 Annual Crop Rotation Practices of CA Smallholder Farmers in Chafukuma

Crop included in Rotation	Farmers including crop (%)
Cereals	
Maize	*100*
Millet	*1.1*
Legumes	
Common beans	100
Soya beans	*32.9*
Green Manure	
Sun hemps	*11.8*

Figure 5.2 Soya *Beans grown in Rotation with Maize in CA field, Chafukuma*

5.4.1.4 Timeliness of Land Preparation in CA, Chafukuma

Interview results with Kansanshi Foundation field officers, farmers and Ministry of Agriculture officers revealed that almost 75 % of the farmers whose fields were studied practiced timeliness in land preparation. They planted their crops by the onset of the first rains from 10th to 28th November annually. The 15 % of the farmers that delayed completed their land preparation and planting by 15th December. The delay was attributed to late acquisition of farming inputs such as certified seed and lime. Both interviews with farmers, Ministry of Agriculture and Kansanshi Foundation field officers and field observations suggested that about 60 % of the pot holes were prepared on time. Handbook for Hoe Farmers in low and medium rainfall areas encourages maize (*Zea mays L*) farmers to plant immediately after the first heavy rain that falls after 15th November (Umar *et al.*, 2011). This entailed that land preparation must have been done during these dates for it to have been considered timely (Umar *et al*., 2011). The results of this study suggest that farmers adhered to timeliness of land preparation in CA according to the messages given to them by experts. The benefits of planting on time were that it led to higher yields which more likely resulted into more crop residues and more organic carbon and associated nutrients added to the soil thereby improving the fertility of the soil (Wolkowski, 2003; Thierfelder and Wall, 2010).

5.4.1.5 Fertilizer and Lime Application

The study found that all the farmers (100 %) who were interviewed applied lime to their CA and CV agriculture managed fields at the rate of 1000 kg per hectare. They also applied urea as top dressing fertilizer and D compound as basal fertilizer at the rate of 200 kg per hectare respectively in both their CA and CV managed fields. However, liming was a common practice in both CA and CV agriculture systems in the area despite most farmers not using large amounts of mineral fertilizers. This could be attributed to the inherently strong acidity (pH 4.2) of the soil characteristic of high rainfall areas (Yerokun, 2008). This finding has not been reported in low and medium rainfall areas (Umar *et al*., 2011; Muchabi *et al*., 2014).

5.5 Comparison of Maize Yields in CA and CV Fields in Chafukuma

Maize yields from CA and CV agriculture managed fields were reported to be different. The yields were higher in CA than CV agriculture managed fields. An average maize yield of 8 tons per hectare were reported by 100 % of the respondents in CA managed fields against an average of 1.6 tons of maize for the same area in CV agriculture managed fields reported by 100 % of the respondents. Out of the interviewed farmers; 76.7 % strongly agreed while 23.3 % agreed that crop yields improved in the last two years of CA practicing in Chafukuma. The claims of higher maize yields in CA than CV fields could not be validated by this study. According to Frake *et al*., (2016) soil fertility is one agronomic factor that determines crop productivity. Nevertheless, it would appear that the claimed high yields in CA managed fields were confounded by large plant population arising from a large number of pot holes in CA managed fields. CA is said to increase yields, improve soil fertility and reduce erosion yet empirical evidence is not clear and consistent on many of these points nor is it always clear which of the principles of CA contribute to the desired effects (Giller *et al*., 2009). Although cases can be found where claims about increased yields (Kabamba *et al*., 2009; Zulu *et al.,* 2000; Wolkowski, 2003) and improvement of soil fertility (Umar *et al*., 2011; Muchabi *et al*., 2014) are supported there are equally convincing scientific reports that contradict these claims (Giller *et al*., 2009). Claims of high maize yields in CA managed fields also have been reported in CA managed fields in low and medium rainfall areas of Zambia (Kabamba *et al*., 2009; Zulu *et al.,* 2000). Concerns about CA include decreased yields often observed in CA and lack of sufficient mulch due to poor productivity and due to the priority giving to feeding of livestock with crop yields (Giller *et al*., 2009). However, good crop yields reported in CA are a plus to residue retention on the fields and have the potential to improve soil fertility through increased plant biomass (Thierfelder and Wall, 2010). Mean maize yields on smallholder farms from conventionally farmed fields for Zambia are generally below two tons per hectare (Zulu *et al*., 2000; Umar *et al*., 2011, IESR, 1999).

5.6 Perceptions on Soil Fertility Benefits Associated with CA

The perceptions of farmers, Kansanshi Foundation and Ministry of Agriculture officers regarding the benefits of CA practices to soil fertility were as presented in the subsections below.

5.6.1 Farmers' Perceptions on Soil Fertility Status of CA and CV Fields

All the farmers interviewed (100 %) mentioned that CA improved soil fertility, crop residue cover, crop yields and soil biota in the fields. The farmers (100 %) claimed that the colour of leaves, state of stems and roots of their crops were better in CA fields than CV managed fields. They attributed this variation to the varying levels of essential chemical elements such as P, K, N and organic carbon in the fields as presented in Table 5.5.

Table 5.5. Farmers' Perceptions of Nutrient Levels in CA and CV Fields in Chafukama

Variable	Indicative nutrient	CA FIELD Estimate (%)			CV FIELD Estimate (%)		
		High	Medium	Low	High	Medium	Low
Proper roots formation	*Potassium*	100	0	0	14.5	45.5	40.0
Strong healthy stems	*Phosphorus*	100	0	0	22.3	54.2	23.5
Green healthy leaves	*Nitrogen*	100	0	0	15.2	60.2	24.6
Dark brownish soil	*Organic C*	100	0	0	5.1	55.9	39.0

When the farmers were asked to give their perceptions of soil fertility of their CV agriculture managed fields, 11.8 % said it was high, 8.8 % said it was medium while the rest (79.4 %) said it was low. When the same farmers were asked to mention the practices they were using on their CV agriculture managed fields in the last two years, 26.5 % said they stopped burning crop residues, 65.5 % mentioned burning of crop residues and liming while 8.0 % did not use any lime. Complete hand hoe inversion of soil was still being practiced by 100 % of the farmers in CV agricultural managed fields. When farmers were asked to suggest what they felt could be done to improve soil fertility of their CV agriculture managed fields and all of them mentioned that they needed to adopt CA practices such as crop rotation, minimum tillage and crop residue retention. Field observations found evidence of some of the farmers (about 11.0 %) practicing crop residue retention and crop rotation on their CV fields. The farmers and key informants perceptions that CA improved soil fertility in the study area were consistent with the empirical evidence from soil analysis results not only of this study but also those reported by Muchabi *et al*., (2014) in low rainfall area of Zambia. Also farmers' perceptions of greener maize plant leaves, stronger healthy stalks, better roots formation and darker brown crumble soils in their CA than CV managed agriculture fields were suggestive of higher levels of total nitrogen, available plant phosphorus, exchangeable potassium and organic carbon in CA than CV managed fields. This was consistent with the soil analysis results.

5.6.2 Kansanshi Foundation's Perceptions

Kansanshi Foundation field officers claimed that soil fertility improved in the fields in which CA was practiced in Chafukuma. Their claims were based on crop yields improvements which they said, using maize yields as an example, were on average 8 ton per hectare compared to 1.6 ton per hectare before CA. There was no evidence of any soil analysis by Kansanshi Foundation to support its claims that CA improved soil fertility.

5.6.3 Ministry of Agriculture's Perceptions

Interviews with Ministry of Agriculture officers in the district revealed that CA improved soil fertility of the agricultural fields where it has been consistently practiced. The officers also revealed that farmers practiced manual CA, crop rotation in which maize was grown in rotation with soya beans, and did not burn crop residues but retained them in their fields. They approximated that 75 % of the farmers practiced CA according to its principles. According to the officers CA was being promoted to enhance soil fertility and agro-ecosystem sustainability. CA was also perceived to improve crop yields, food security and incomes among households but there was no evidence to support this claim.

Key informant interview with an agronomist in Solwezi, revealed that because of the many benefits associated with CA, Conservation Agriculture Scaling-Up (CASU); a project funded by FAO was supporting CA through the provision of farming inputs and training to lead farmers. The lead farmers were the ones who were being given inputs to set up demonstration plots. Each lead farmer was to recruit 15 follower farmers who would learn CA technologies in the farmer field schools. The demonstration plots for the lead farmers served as Farmer Field Schools. In the district there were 28 lead farmers drawn from each one of the six farm camps which were currently there. The Ministry of Agriculture provides technical support in agronomic training to farmers through farmer field schools.

This study's results therefore suggest that CA practices can improve chemical soil fertility as well as reduce soil acidity in high rainfall areas of Zambia. However, this being the first study in a high rainfall area, further similar studies that compare several CA systems can be scaled up in other high rainfall agro-ecological zones (areas) of the country to validate these results.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The main objective of this study was to determine whether the practice of conservation agriculture (CA) improved soil fertility on smallholder farmers' agricultural fields. The evidence was collected from empirical data from soil analysis of selected chemical soil fertility parameters, farmers' perspectives through interviews and field observations. The study showed evidence of CA associated improvements in plant available P 4.8 mg/kg (26.09 mg/kg to 21.29 mg/kg), exchangeable K 3.23 cmol/kg (11.97 cmol/kg to 8.74 cmol/kg), total N 0.73 % (0.96 % to 0.23 %), SOC 1.79 % (3.31 % to 1.52 %) and pH 0.30 (5.49 to 5.19) levels in CA compared to CV managed fields. Paired sample T-Test analysis shows that the nutrient levels in CA and CV agriculture managed fields were statistically significantly different at $p \leq 0.05$ level of significance. The study further established that the CA practicing smallholder farmers in the area employed minimum tillage, crops residue retention and crop rotation soil management technologies in their fields. These practices were probably responsible for chemical soil fertility improvement in the area. However, there was very little crop diversification. Crop rotations were also not diversified. The farmers and key informants perceptions were that CA practice improved soil fertility in the fields where it had been practiced. Inferring from these results, it was concluded that CA practice improved chemical soil fertility of agricultural fields in a high rainfall area and could be scaled up in the other high rainfall areas of Zambia provided all the important agronomic practices are utilized consistently.

6.2 Recommendations

Arising from the results of this study the following recommendations are made:

1. Kansanshi Foundation should encourage its CA practicing farmers to diversify crop rotations and to retain sufficient amounts of biomass in the fields after harvest.
2. Recommendation for future studies: This study did not look at the sustainability and assessment of socio-economic benefits of CA for smallholder farmers in Solwezi. It also did not measure crop yields. These are aspects which other researchers can consider exploring, especially in a context without material support from an organization.

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APPENDICES

APPENDIX A: INTERVIEW SCHEDULE ON EFFECTS OF CONSERVATION AGRICULTURE ON SOIL FERTILITY OF AGRICULTURAL FIELDS IN CHAFUKUMA, SOLWEZI, ZAMBIA, FOR RANDOMLY SELECTED CA PRACTICING SMALLHOLDER FARMERS

Respondent No.: ---------- Location of respondent: ---

Study site: -- Date: -------------------------------------

Mr. SAKAMBUTA JOSHUA is carrying out a study on effects of conservation agriculture on soil fertility of agricultural fields of smallholder farmers in Chafukuma, Solwezi, Zambia. This is in partial fulfilment of the requirement for the degree of Master of Science in Environmental and Natural Resources Management with the University of Zambia. You have been randomly selected to assist with information in this interview. Participation in this interview is voluntary and you will be kept anonymous when results are presented. Please tick /write in the appropriate space provided.

Bio data

1. Sex : M [ ] F [ ]
2. Age -------------------------------- years
3. Marital status: Married [ ] Single [ ] Divorced/separated [ ] Widowed [ ]
4. Level of education attained:
   Never been to school [ ] Primary [ ] Secondary [ ] Tertiary [ ]
5. Major source of household income---

A. Background information about the farmer

6. How long have you been practicing CA with support from Kansanshi Foundation?
   Less than 5 years [ ] 5 years [ ] More than 5 years [ ]
7. Have you been practicing CA on the same field or different fields over this period?
   Same field [ ] Different field [ ]

B. CA practices among smallholder farmers in Chafukuma

8. What CA practices have you been using on your field since your adoption of CA?
   Minimum tillage [ ] Crop residue retention [ ] Crop rotation [ ] Any other-----------------

9. What type of practices have you been using under:
   (a) Minimum tillage: Basins [ ]   Pot holing [ ] Any other [ ]
   (b) Crop residue retention: Cover crops [ ] Crop stalk/ mulch [ ] No burning []
   (c) Crop rotation: Cereal- legume [ ]   Green manuring [   ] Any other --------
10. What are your main reasons for adopting:
    (a) Minimum tillage? Improve soil fertility [   ] Reduce soil erosion [   ] Increase yields [   ] Any other ---
    (b) Crop residue retention? Improve soil fertility [ ] Reduce soil erosion [   ] Increase yields [   ] Any other ---
    (c) Crop rotation? Improve soil fertility [ ] Reduce soil erosion [ ] Increase yields [ ] Any other---
11. Do you add any soil improving inputs to the soil on your field?
    Yes [   ]   No   [   ]
12. What are these inputs? Please specify the inputs.
    Agricultural lime [ ] Mineral fertilizer [ ] Manure [ ] Others (please specify) --------------
13. When do you add these inputs to the soil?
    Before planting [   ] During planting [ ] After planting [ ] Any other---------------
14. Why do you add these inputs to the soil at the time stated?
    Improve soil fertility [ ] Neutralize soil acidity [ ] Improve crop yields [ ]
15. Have you been using lime on your field? Yes [   ]   No [   ]
16. If your answer to question 15 is yes, what is the main reason for applying lime on your field?
    Neutralize acid in soil [ ]   Any other ---
17. What is the source of your fertilizer and lime?
    Government [ ]   Kansanshi Foundation [ ]   Any other --
18. What kind of crops have you been growing on your field in the last 2 years?
    Maize [ ] Groundnuts [ ] Common beans [ ] Soya beans [ ] Millet [ ] Any other --------
19. What are the main reasons for growing each of the crops you have named on your field?
    Consumption [ ] Improve soil fertility [ ] Improve crop residue retention [ ]

C. Effects of CA Practices on Soil Fertility of smallholder farmers' agricultural fields in Chafukuma

20. How would you rate the following parameters of soil fertility of your CA field on a 5 point scale of very high to very low?

Soil Fertility Parameter	Representative parameter	Level of Parameter in soil in CA Field				
		Very high	**High**	**Medium**	**Low**	**Very low**
Dark brown soil colour	Soil organic matter					
Amount of lime used	pH					
Green Healthy leaves	Nitrogen					
Proper roots formation	Potassium					
Health strong stems	Phosphorous					

21. How would you rate the following soil fertility parameters of soil of your CA field?

Soil Fertility Parameter	Level of Parameter in soil in CA Field				
	Very high	**High**	**Medium**	**Low**	**Very low**
Crop residue cover					
Soil organisms					
Crop yields per ha (Kg)					
Nutrient availability (N,P,K)					

22. What is your opinion on the contribution of CA to soil fertility of your field? CA practices have significantly improved the following parameters in the field?

Soil Fertility Parameter	**Smallholder farmers' perceptions of soil fertility improvement by CA**				
	Strongly agree	Agree	No opinion	Disagree	Strongly disagree
Crop yields					
Soil nutrients					
Soil pH					
Soil fertility					

23. Crop yields have significantly improved in the last 2 years?

    Strongly agree [ ] Agree [ ] Disagree [ ] Strongly disagree [ ]

D. Investigating farmers' perceptions on benefits to soil fertility associated with CA practice in Chafukuma

24. What benefits to the soil can you associate with CA on your field?

    Improved fertility [ ] improved residue cover [ ] improved biota [ ] improved yields [ ] Others (please specify) ---

E. Investigating level of soil fertility of Conventional (CV) (traditionally managed) agriculture fields of smallholder farmers in Chafukuma

25. Apart from CA managed fields do you own other fields which are traditionally (conventionally) managed?

    Yes [ ]   No [ ]

26. If your answer to question 25 is yes answer question 26 and 27. Are there any of these conventional fields that are close to your CA managed fields?

    Yes [ ]   No [ ]

27. Please estimate the distance in terms of closeness in metres.

---

28. What kind of practices do you use on these CV managed fields?

    ----

29. How would you rate the soil fertility of your conventionally managed (CV) fields?

    High [ ]   Medium [ ]   Low [ ]

30. How would you rate the following soil fertility parameters of your conventional managed fields? (please tick in appropriate area in the table)

Soil Fertility Parameter	**Level of Parameter in soil in CV managed Field**				
	Very high	High	Medium	Low	Very low
Crop residue cover					
Crop yields per ha (Kg)					
Surface runoff					
Nutrient level (N,P,K)					

31. What crops have you been growing on the conventional field?

    Maize [ ] Groundnuts [ ] Common beans [ ] Any other -----------------------

32. What have been the yields like in the last 2 years from your conventional field? Please suggest yields in tons per Lima.--
33. What do you think can be done to improve the yields on the conventional field?

    Practice diversified crop rotation [ ] Practice minimum tillage [ ] Practice crop residue retention [ ] Practice conservation agriculture [ ]

End of interview.

APPENDIX B: INTERVIEW SCHEDULE ON EFFECTS OF CONSERVATION AGRICULTURE ON SOIL FERTILITY OF AGRICULTURAL FIELDS IN CHAFUKUMA FOR PURPOSIVELY SELECTED KANSANSHI FOUNDATION STAFF

Mr. SAKAMBUTA JOSHUA is carrying out a study on effects of conservation agriculture on soil fertility of agricultural fields of smallholder farmers in Chafukuma, Solwezi, Zambia. This is in partial fulfilment of the requirement for the degree of Master of Science in Environmental and Natural Resources Management with the University of Zambia. You have been purposively selected to assist with information in this interview. Participation in this interview is voluntary and you will be kept anonymous when results are presented.

Date: --

1. Personal Information of respondent
   Name: --- Age ---------------- (years)
   Level of education attained --
   Occupation--
   Position---
   Role --
2. For how long has Kansanshi Foundation been promoting conservation agriculture in Chafukuma?
   Less than 5 years [ ]   5 years [ ]   more than 5 years [ ]
3. What is the main reason for promoting conservation agriculture among smallholder farmers in Chafukuma?

   ----
4. What conservation practices has Kansanshi Foundation been promoting among smallholder farmers in Chafukuma?
   Minimum tillage [ ] Crop residue retention [ ] Crop rotation [ ] Use of manures [ ]
   Any other --

5. What specific conservation agriculture practices has Kansanshi Foundation been promoting in Chafukuma under:
   (i) Minimum tillage---
   (ii) Crop residue retention---
   (iii) Crop rotation ---
   (iv) Fertilizers --
   (v) Any other---
6. What are the major reasons for promoting these conservation agriculture practices in Chafukuma?

   ----
7. What kind of crops has Kansanshi Foundation been promoting for growing among smallholder farmers in Chafukuma for the past 5 years?

   ----
8. What are the major reasons for promoting the growing of these crops under conservation agriculture in Chafukuma?

   ----
9. What benefits to the soil would you attribute to conservation agriculture as promoted among smallholder farmers by Kansanshi Foundation in Chafukuma?

   ----
10. How would you rate the following parameters of soil fertility of CA fields after 5 years of practice on a 5 point scale of very high to very low?

Soil Fertility Parameter	**Level of Parameter in soil in CA managed Field**				
	Very high	High	Medium	Low	Very low
Level of Crop residue cover					
Number of soil organisms					
Crop yields per ha (Kg)					
Nutrient levels (N,P,K)					

11. Has CA practices significantly improved soil fertility of your field?

Soil Fertility Parameter	**Smallholder farmers' perceptions on soil fertility in CA**				
	Strongly agree	Agree	No opinion	Disagree	Strongly disagree
Crop yields					
Soil nutrient content					
Soil pH					
Soil fertility in general					

12. Have any soil assessments been conducted by Kansanshi Foundation to ascertain the benefits of conservation agriculture to the soil in Chafukuma since its adoption?

    Yes [ ] No [ ]

13. If no what is the source of evidence for the observations in question 12, 13 and 14 above?

    ----

14. How does Kansanshi Foundation help the smallholder farmers?

End of interview

Thank you so much for your time and input!

APPENDIX C: SOIL ANALYSES RESULTS ATTACHMENT

Data Set Soil analysis P ($mgkg^{-1}$)

Pair	CA Field	CV Field
1	20	20
2	24	20
3	28	24
4	38	36
5	26	20
6	28	20
7	38	24
8	20	20
9	24	20
10	28	20
11	20	20
12	20	20
13	24	20
14	38	20
15	26	20
16	28	20
17	24	20
18	24	20
19	26	20
20	38	36
21	28	24
22	24	24
23	21	16
24	26	20
25	26	19
26	26	20
27	19	16
28	24	20
29	24	20
30	24	20
31	24	19
32	22	19
33	28	20
34	24	20

Data Set Soil analysis SOC (%)

Pair	CA Field	CV Field
1	3.5	1.5
2	3.5	1.6
3	3.8	1.8
4	2.7	1.2
5	2.7	1.2
6	2.8	1
7	3.6	1.1
8	3	1.2
9	3.4	1.2
10	3.3	1.8
11	3.6	1.5
12	3.3	1.5
13	3.4	1.8
14	3.4	2
15	3.3	1.6
16	3.5	1.5
17	3.6	1.8
18	3.3	2
19	3	1.7
20	3.4	1.3
21	3.6	1
22	3.3	1.7
23	3.2	1.5
24	3.6	1.8
25	3.4	1.6
26	3	1.3
27	3.3	1.3
28	3.4	2.1
29	3.6	1.2
30	3.4	1.2
31	3.3	1.1
32	3.3	1.8
33	3.1	1.9
34	3.1	1.9

Data Set Soil Analysis K ($cmolkg^{-1}$)

Pair	CA Field	CV Field
1	13.2	6.4
2	13.8	10.6
3	8.6	6.4
4	13.6	6.4
5	15.4	6.4
6	6.4	6.4
7	13.2	6.4
8	13.8	6.4
9	8.6	6.4
10	8.6	6.4
11	13.6	6.4
12	15.4	10.4
13	6.4	5.9
14	13.2	10.4
15	13.8	10.4
16	13.6	10
17	13.2	10
18	1.1	10.4
19	13.8	10.6
20	13.6	10
21	13.6	10.6
22	15.4	10.6
23	13.2	10.4
24	15.4	10.6
25	6.4	6.4
26	6.4	6.4
27	8.6	6.4
28	8.6	6.4
29	8.6	6
30	8.6	6
31	8.6	6.4
32	13.6	10.4
33	13.8	10.4
34	15.4	13.8

Data Set Soil Analysis N (%)

Pair	CA Field	CV Field
1	0.99	0.17
2	0.55	0.17
3	0.65	0.15
4	1.19	0.22
5	0.7	0.22
6	0.8	0.17
7	0.87	0.15
8	0.85	0.17
9	0.85	0.15
10	0.85	0.15
11	0.87	0.17
12	0.8	0.17
13	0.97	0.17
14	0.86	0.17
15	0.8	0.25
16	0.85	0.17
17	0.85	0.15
18	0.86	0.22
19	0.89	0.25
20	0.89	0.25
21	0.89	0.17
22	0.86	0.17
23	0.89	0.17
24	1.25	0.87
25	1.25	0.87
26	1.25	0.85
27	1.25	0.15
28	1.27	0.17
29	1.25	0.17
30	0.99	0.17
31	1	0.1
32	1.25	0.1
33	1.25	0.2
34	1	0.1

Data Set Soil Analysis pH (1-14)

Pair	CA Field	CV Field
1	5.0	4.8
2	5.4	5.1
3	5.0	5.0
4	5.8	5.4
5	6.3	6.1
6	5.4	5.0
7	5.5	5.1
8	5.5	5.4
9	5.5	5.1
10	5.0	4.8
11	5.5	5.0
12	5.5	5.4
13	5.5	5.5
14	5.7	5.5
15	5.5	5.1
16	5.5	5.1
17	5.7	5.3
18	5.0	5.0
19	5.5	5.0
20	5.5	5.2
21	5.5	5.5
22	5.8	5.5
23	5.5	5.0
24	5.4	5.1
25	5.8	5.4
26	5.5	5.4
27	5.0	4.8
28	5.5	5.1
29	5.1	4.9
30	5.0	4.8
31	5.5	5.5
32	5.4	5.0
33	5.5	5.0
34	5.4	4.1

APPENDIX D: INTERVIEW GUIDE FOR PURPOSIVELY SELECTED DISTRICT AGRICULTURE OFFICERS

Position: --

Station: --

Main responsibility: ---

Date: ---

1. Is the Department of Agriculture in the district promoting CA amongst smallholder farmers?

   ----

2. Are there other organizations that are promoting CA in the district?

   ----

3. What CA practices / principles are being promoted by the department and other promoter organizations among smallholder farmers in the district?

   ----

4. What are the main reasons for promoting these CA practices among smallholder farmers in the district?

   ----

5. What are your perceived CA benefits to soil chemical fertility in the district?

   ----

6. What are the effects of CA practices on chemical soil fertility on agricultural fields of smallholder farmers in the district?

   ----

7. Why is the Department of Agriculture promoting CA among smallholder farmers in the district?

THE END

APPENDIX E: FIELD OBSERVATION SHEET

AREA: ---

DATE: --

OBSERVER: ---

1. CA practices employed on the fields.

   ----

2. Levels/ amounts of mulch/ crop residue cover in the fields.

   ----

3. Types of crops grown in rotation in the fields.

   ----

4. Sizes of fields under CA in hectares.

   ----

5. Crop yield levels per hectare in CA and CV fields (estimates only).

   ----

6. Soil colour in CA and CV managed fields.

   ----

7. Challenges in CA managed fields.

THE END