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Sustainable Agricultural Mechanization of Conservation Agriculture in Smallholder Kenyan Maize Farmers for Sustainable Intensification and Increased Climate Resilience

Abstract

Food-insecurity is a complex global challenge of the past, present and future, underpinned by a combination of social, economic, and environmental factors. Population-growth poses one of the greatest challenges to food-security in regions with high expected population growth, low agricultural productivity, and pre-existing food insecurity issues. Sub-Saharan Africa, having the highest expected population growth trend over the next century, pre-existent proliferation of low-productivity systems and undernourishment, faces marked threat from the effects of climate change on its agricultural sector, especially in rain-fed smallholder farms, whom produce a majority of food in sub-Saharan Africa. The apparent need for sustainable development synergistically addressing these diverse challenges in the agricultural sector is a necessity for heightened, rather than worsened, food-security outcomes as both climate change effects and population growth increase in intensity and scale over the next century.

Upscaling of sustainable-intensification systems such as conservation agriculture, which has shown great capacity to increase farm productivity and climate-resilience while reducing environmental degradation, has yet seen limited uptake in sub-Saharan Africa despite its potential. The purpose of this study is to examine challenges and successes of sustainable agricultural mechanization of conservation agriculture, a vital component of the innovation's success, by conducting a location-based case-study in Laikipia, Kenya. Areas in need of attention were: finance, extension services, and equipment access. Recommendations for issue remediation were developed from stakeholder interviews conducted in the case study, and findings from examination of mechanization success-stories in other countries and systems. Continued examination of trends across different communities and contexts will support a more robust, exhaustive understanding of mechanization challenges and opportunities, thereby enabling informed policy-making and project design for upscaling conservation agriculture.

Acknowledgements

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List of Abbreviations

ADB- African Development Bank

ACT- African Conservation Tillage Network

AGRA- Alliance for Green Revolution in Africa

AM- Agricultural Mechanization

AR5- Assessment Report 5

AUC- African Union Commission

BARI- Bangladesh Agricultural Research Institute

CA- Conservation agriculture

CASPP- Conservation Agriculture Scaling Up for Productivity and Production

CA4FS- Conservation Agriculture for Food Security

CIMYYT- Wheat and Maize Improvement Centre

CIRAD- French Agricultural Research Centre for International Development

CSA- Climate SMART Agriculture

ESA- Eastern and Southern Africa

FACASI- Farm Mechanization & Conservation Agriculture for Sustainable intensification

GHG- Greenhouse Gas

ICAAP- International Conservation Agriculture Advisory Panel for Africa

ICRAF- World Agroforestry Centre

IDE- International Development Enterprises

IPCC- Intergovernmental Panel on Climate Change

KARI- Kenyan Agricultural Research Institute

KENDAT- Kenyan Network for Dissemination of Agricultural Technologies

MAL- Ministry of Livestock and Agriculture (Zambia)

MTZL- Mobile Transaction Zambia Limited

PPP- Public-private partnership

SAM- Sustainable agricultural mechanization

SME- Small-medium enterprise

SSA- Sub-Saharan Africa

OSC- Organic soil-carbon

WFP- World Food Programme

2WT- Two-wheel tractors

4WT- Four-wheel tractors

Chapter 1: Introduction

1.1 Introduction

This chapter investigates the relations between unsustainable land-use and climate change, as related to the wider food insecurity issue, as well as how 'win-win' climate change adaptation activities are necessitated, especially for vulnerable food-production systems and dependant populations, considering climate-impact predictions for the next century. This is followed by a review of the potential of conservation agriculture (CA) as a viable, climate-smart strategy for sustainable intensification in rain-fed smallholder agri-systems in sub-Saharan Africa, and the value-adding potential of sustainable agricultural mechanization (SAM) in upscaling and enhancing CA and CA co-benefits within these systems. The chapter will finish with the study's rationale, significance, research topics, and organization.

1.2 Linking Food-security, Population Growth, and Climate Change

Food security is defined by the World Food Programme (WFP) as having consistent availability and sufficient access to safe, nourishing food; this involves three elements: availability, access, and utilization (WFP, 2015). Food-insecurity, or, inadequate availability, access and/or utilization of foodstuffs is one of the most persistent issues facing humanity's past, present and future; according to the United Nations Food and Agriculture Organisation (FAO), approximately 795 million people were undernourished in 2015 (FAO, 2015). While this issue is multi-pronged in nature, and may stem from a range of location-specific factors such as land/resource degradation, population-growth, and political instability, climate change is a serious, transnational threat to food production systems across the world (Schmidhuber & Tubiello, 2007). The Intergovernmental Panel on Climate Change's (IPCC) Fifth Assessment Report (AR5) indicates it is "extremely likely" that anthropogenic climate change, defined as changes in the climate due to human activity (IPCC, 2014), is the overarching cause behind the steady rise in atmospheric CO_2 concentrations (Fig. 1.1) and average global surface temperature since the 1950s (IPCC, 2014). Emission of heat-trapping greenhouse gases (GHGs) through various activities has resulted in an average warming of 0.85 °Cover all land and ocean surfaces (IPCC, 2014).

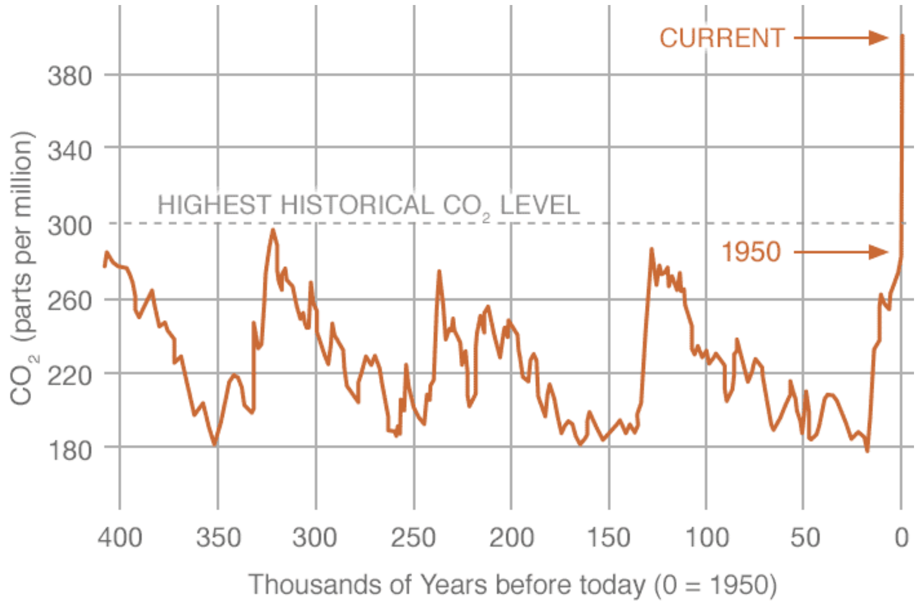
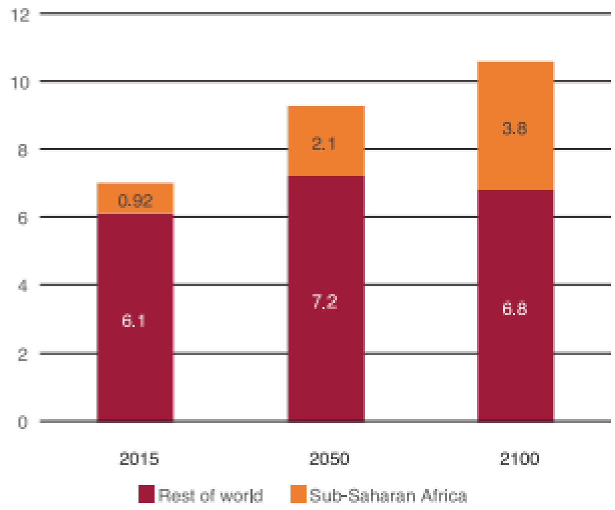


Figure 1.1: Carbon di-oxide parts per million (ppm) over geologic history to present day (NASA, 2017).

Climate change, by nature, poses one of the greatest future threats to the agriculture sector and global-food security, owing to the fundamental relationship between climatic conditions and agri-system productivity (Adams et al., 1998); impacts are already actualizing in the food-systems across the world (FAO, 2008). Generalized bio-physical effects of climate change on the agriculture sector has been altered precipitation patterns, loss of fertile coastal lands because of rising sea-level, increased pest shifted growing seasons, increased extreme weather events, and unpredictable farming conditions; this has led to decreased food-security in vulnerable regions and populations (Palombi & Sessa, 2013). Climate-risks and disasters have widely varying impacts and intensities on different regions and population demographics, but generally have disproportionately negative effects on already food-insecure populations (WFP, 2017).

1.3 Food-security in sub-Saharan Africa

Presently, Sub-saharan Africa (SSA) is home to over 200 million undernourished people; it is the only region of the word for which food-security is expected to worsen over the next two decades without drastic intervention (Kidane et al., 2006). The overall historical trend of SSA has been that of agricultural output being outstripped by population growth (Kidane et al., 2006). With the highest projected population growth, by the end of the century (Fig 1.2), there will be over almost 2 billion more people to feed in SSA (AGRA, 2016).



Notes: The estimated population for SSA was 12.3 percent of the world's population in 2015, and is projected to comprise 21.7 percent in 2050 and 34.0 percent in 2100.

Figure 1.2: Population projections for sub-Saharan Africa as compared to the rest of the world; 2015, 2050, 2100 (United Nations, 2016).

Currently, the SSA region is experiencing the most pronounced climate-induced impacts on food-security (Fig. 1.3), especially in arid and semi-arid areas (AGRA, 2014). Differential precipitation and temperatures have already negatively affected each of the three elements of food-security (food availability, food accessibility, and food utilization) (Zewdie et al., 2014). A high proportion of the population in SSA is dependent, either directly or indirectly, on the climate sensitive agricultural system, especially rain-fed smallholder (defined as farmers owning less than 10 hectares land (FAO, 2013)) farmers. Being that over 80 percent of farmland in SSA is managed by smallholders, and smallholders produce most of the food consumed in SSA (FAO, IFAD &WFP, 2015), food-security effects are not localised to the farmers themselves, rather, they are far-reaching.

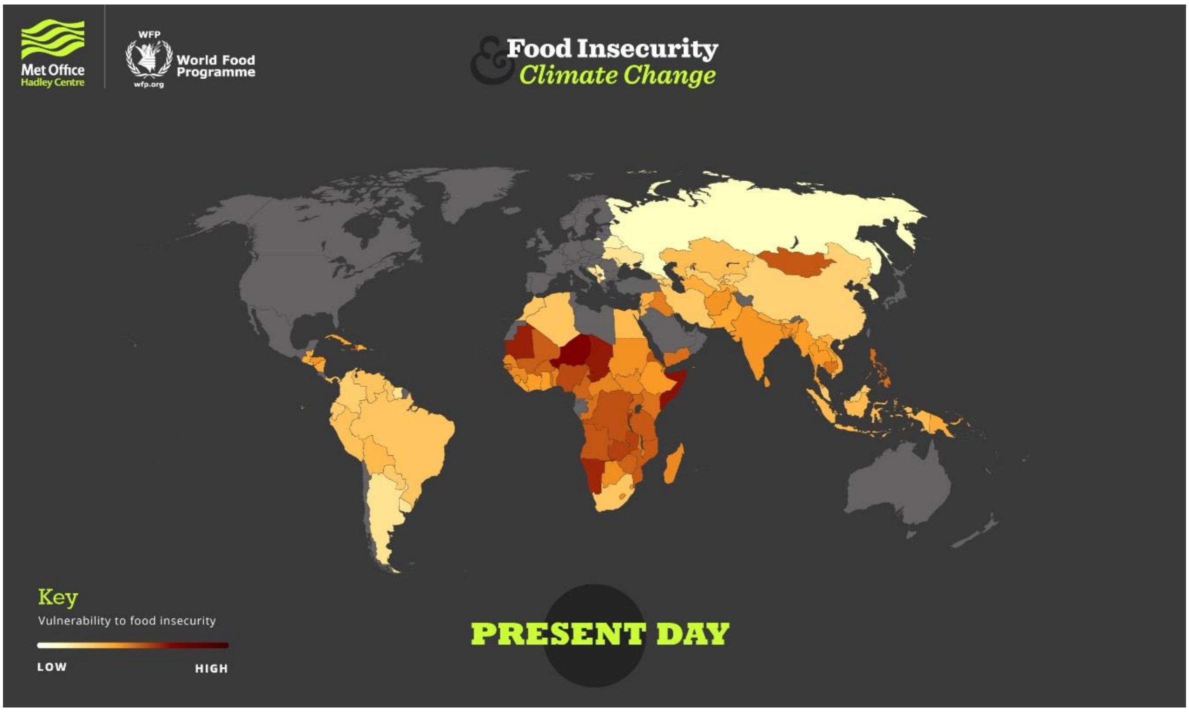


Figure 1.3: Index for vulnerability to food insecurity due to climate change effects, present day (World Food Programme and Met Office, 2017)

1.4 Kenyan Smallholder Maize Farming

The Republic of Kenya, with a smallholder farming population comprising 34.5 percent of the overall population (Rapsomanikis G., 2015, Ogada et al., 2014) will be the subject of this study. Smallholders in Kenya are a vital part of the Kenyan economy and food production system, contributing approximately 75 percent of national food production total, and 70 percent of total marketed produce (Rapsomanikis G., 2015, Ogada et al., 2015). An overwhelming majority of smallholder farms produce *Zea mays* (Fig. 1.4) (hereafter referred to as 'maize'), which is a staple crop for over 90 percent of the Kenyan population (Mati, 2000). Like many other regions of SSA, smallholder agri-systems are characterized by low-productivity, or, having a low ratio of agricultural outputs to agricultural inputs (Kibaara et al., 2009). Primary drivers behind this phenomenon are declining soil fertility, frequent drought, and irregular precipitation patterns (Ogada et al.,2015). As a result, overall agricultural productivity in Kenya has been declining while population has been increasing (Ogada et al., 2015). It is important to note that the average Kenyan smallholder is resource poor; while 42 percent of the Kenyan population lives under the poverty line, well over half this demographic is made up of smallholder farmers across the nation (Fig 1.5). By consequence underproductivity and low-yield seasons have large impacts on the food security of the farmers, as Kenyan smallholder farmers' main food source is derived from their own cultivated products (Rapsomanikis G., 2015).

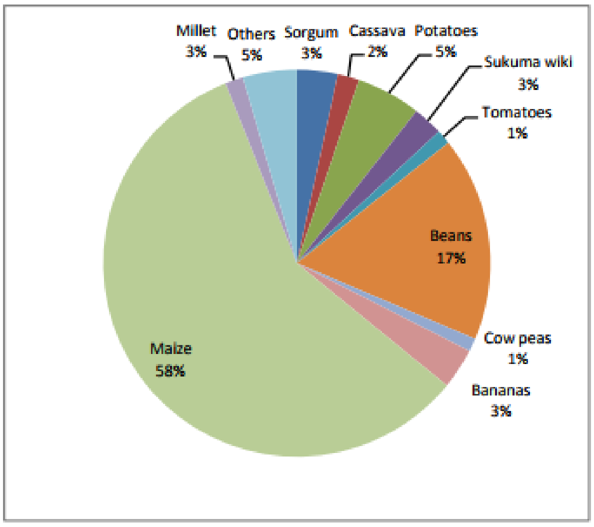


Figure 1.4: Breakdown of smallholder farm products in Kenya (Rapsomanikis G., 2015).

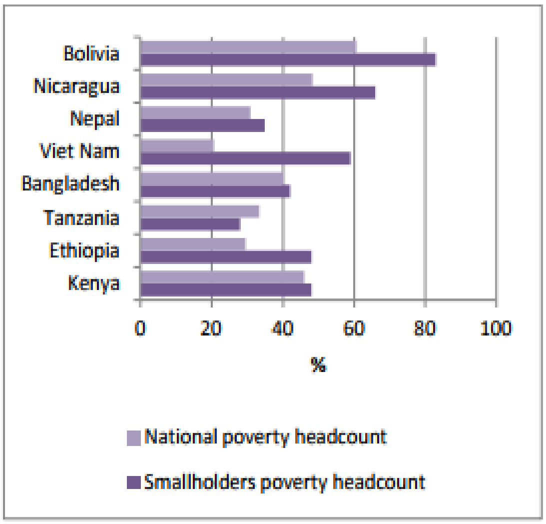


Figure 1.5: Poverty Headcount ratio at national poverty line- smallholders as compared to the national headcount (Rapsomanikis G., 2015).

The next section will explore the specific projected impacts of climate change in Kenya, with specific focus on maize-production impacts.

1.5 Kenya Climate Predictions and Maize Agriculture Impacts

The Met Office Hadley Centre's report "Climate: Observations, projections and impacts: Kenya" (Gosling et al., 2011) predicted future climate conditions in Kenya as per the Intergovernmental Panel on Climate Change Assessment Fourth Assessment Report (IPCC AR4) model projections. The national predictions for Kenya were based on temperature and precipitation predictions, which were then extrapolated to envisage future crop-yield, food-security and water stress/drought changes (Gosling et al. 2011). The results of the study are summarized below:

1.5.1 Climate Change Projections:

Temperature:

- Since 1960, widespread warming in average temperatures has been observed across Kenya (Gosling et al. 2011)
- The IPCC AR4 AIB emissions scenario and Global Climate Modelling (GCM) CMIP3 model data concur temperature increases of 0.8 and 1.5 °C by the 2030s,

1.6 to 2.7 °C by 2060, and up to 3°C by year 2100 across Kenya as compared with the 1960-1990 baseline (Gosling et al. 2011)

Precipitation**:**

- Quantitatively, precipitation will remain relatively stable; distribution, however, will vary. The short-rains season (October- January) will receive increased rainfall while the long-rains season will receive less precipitation (Gosling et al., 2011)

1.5.2: Impacts projections

Crop-yield (Maize):

According to the Met Office, "The majority of global- and regional-scale studies… generally project yield declines with climate change for the country's most important staple crops; maize and beans" (Gosling et al. 2011). Maize growth is influenced by humidity, day-length, solar radiation, temperature and precipitation, with precipitation distribution and volume being the most limiting factor for maize cultivation potential in semi-arid regions of Kenya (Mati, 2000). Despite precipitation levels remaining relatively stable, higher temperatures will negatively impact available soil moisture and evapo-transpiration (Mati, 2000).

A further study by Iglesias and Rosenwing (2009) modelled staple-crop (wheat and maize) response to the A1F1, A2a, A2b, A2c, B1a, B2a, and B2b emissions scenarios of the IPCC (2000) Special Report on Emissions Scenarios for years 2020, 2050, and 2080 relative to baseline production (1970-2000) in Kenya. The simulation controlled for the effect of carbon fertilization and incorporated the current adaptive potential of Kenya to reach optimum yield levels (Iglesias & Rosenwing, 2009). While wheat increased in each scenario in the short-term (until 2020) before declining in 2050 and 2080, maize underwent uniform decline (Fig 1.6).

Scenario	Year	Wheat	Maize
A1FI	2020	1.40	-1.60
	2050	-4.07	-11.07
	2080	-17.41	-27.41
A2a	2020	2.24	-0.76
	2050	-1.84	-8.84
	2080	-7.79	-18.79
A2b	2020	1.91	-1.09
	2050	0.43	-6.57
	2080	-7.45	-18.45
A2c	2020	2.71	-0.29
	2050	1.39	-5.61
	2080	-6.27	-17.27
B1a	2020	1.78	-1.22
	2050	-0.87	-5.87
	2080	-4.77	-10.77
B2a	2020	0.82	-2.18
	2050	-1.80	-6.80
	2080	-6.77	-13.77
B2b	2020	0.86	-2.14
	2050	-2.99	-7.99
	2080	-4.36	-11.36

Figure 1.6: Maize and wheat yield change (%) for IPCC emissions-scenarios in 2020, 2050, and 2080 (Iglesias & Rosenwing, 2009).

1.6 The Necessity of Win-Win Adaptation Strategies for Smallholder Farmers in Kenya

The almost certain yield loss of the most important staple-crop in Kenya, and consequences of decreased food security and poverty of resource-poor, smallholder-dense areas, illustrates the need for adaptation strategies to address climate induced threats for smallholder farming communities. Well-designed adaptation strategies have been shown to have a meaningful impact on climate resilience capacity; research by the WFP and Met Office (2017) indicates high adaptive investment can have greatly beneficial impacts on future food-security realities (Figs. 1.6, 1.7).

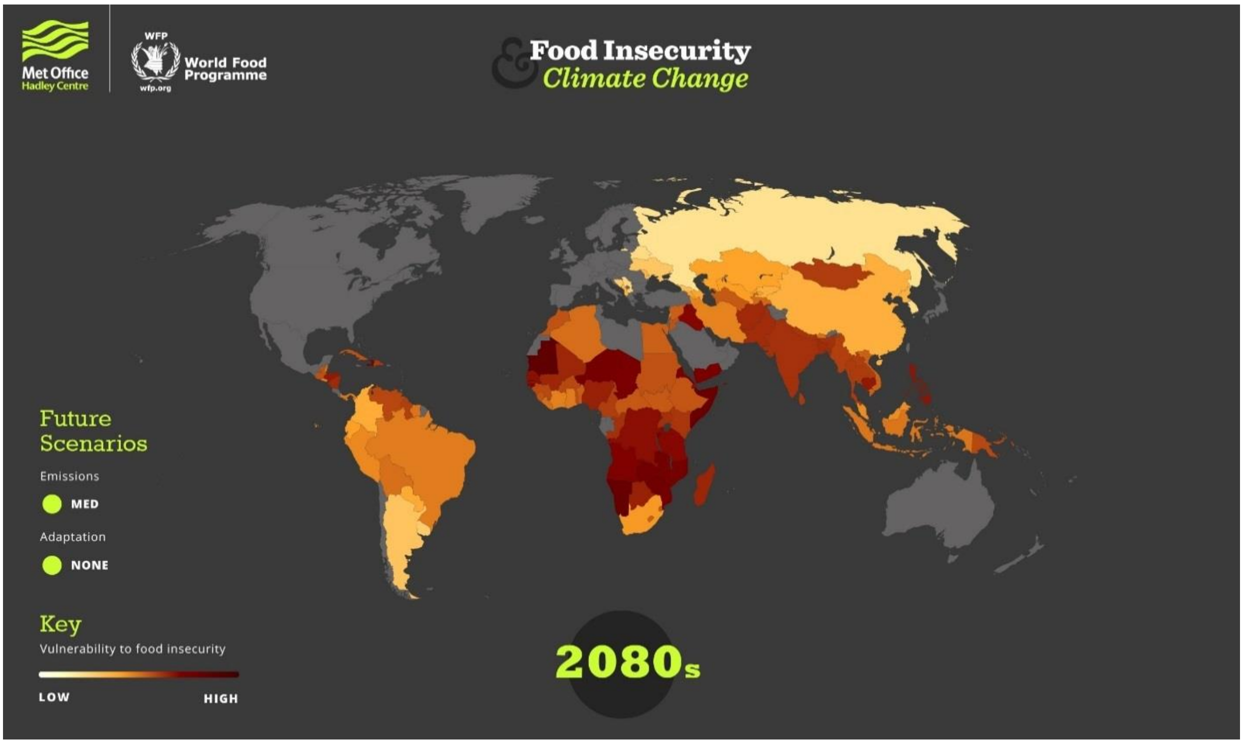


Figure 1.6: Index for vulnerability to food-insecurity due to climate change effects: medium emissions pathway (RCP 4.5), no adaptation (adaptive capacity is kept at present day levels), 2080s (World Food Programme and Met Office, 2017).

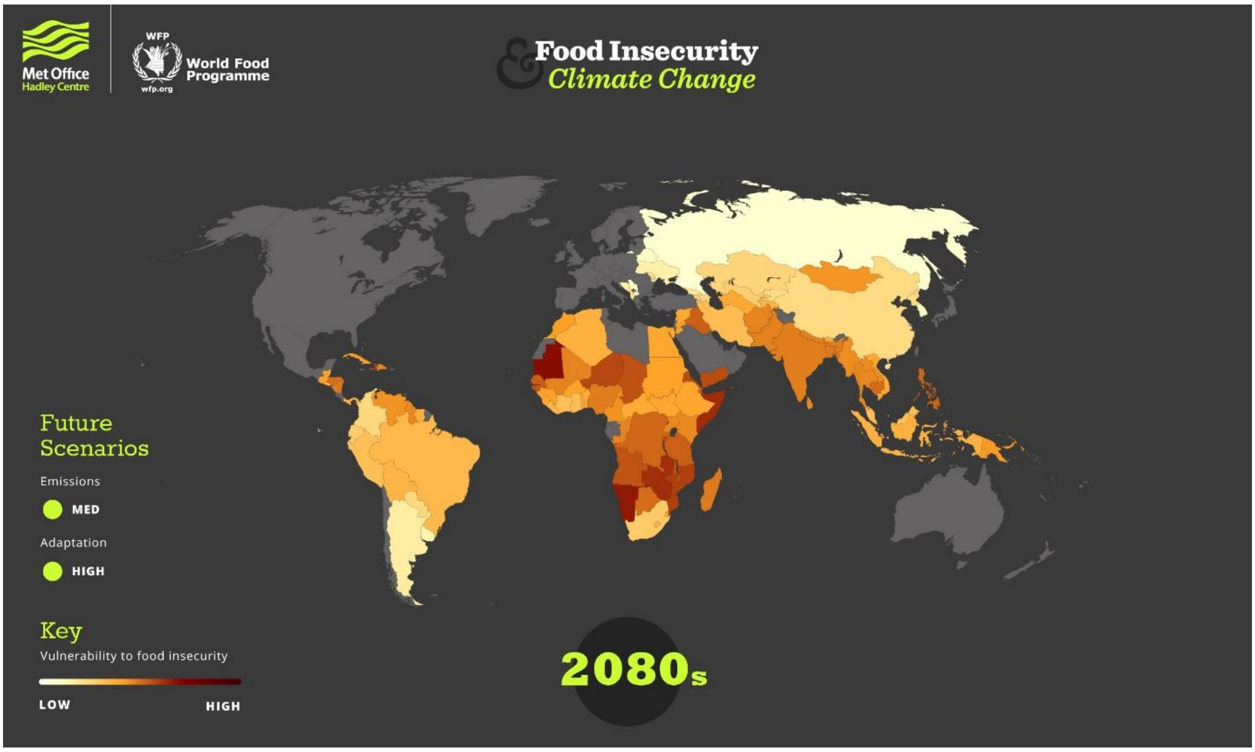


Figure 1.7: Index for vulnerability to food-insecurity due to climate change effects: medium emissions pathway (RCP 4.5), high adaptation (adaptive capacity change of 20-30 percent), 2080s (World Food Programme and Met Office, 2017).

Water-conservation strategies for farms hold particular promise for impactful adaptation in Kenya due to multiple factors:

1. Eighty percent of Kenya is an arid/ semi-arid agri-zone (FAO, 2016)
2. A majority of climate predictions indicate future increases of erratic rainfall pattern (Gosling et al., 2011)
3. High prevalence of rain-fed smallholder farms (Rapsomanikis G., 2015)
4. ‘Medium-high’ sensitivity of maize to water shortage and stress (FAO, 2017).

An efficient adaptation strategy would concomitantly address the other main biophysical constraints to productivity; that is poor soil fertility and invasive weed/pest crop infection (Tadele, 2017). Soil degradation is a major danger to both agricultural productivity and environmental quality (Lal, 1993). Most soils in Africa face low fertility due to poor soil-management and removal of crop residues (Tadele, 2017). This results in soil compaction, nutrient- leaching, increased salinity, soil erosion and lowered water infiltration and holding capacity (Lal, 1993). These factors can have negative bearing on both quantity and quality of cultivated agricultural products, as well as larger environmental issues such as sedimentation of waterways (Lal, 1993). Additionally, since soil is the largest terrestrial carbon-sink on the planet, soil-disturbance with activities such as mechanically tilling carbon-rich soil releases GHGs, effectively converting a carbon sink to a carbon emissions source. Lastly, for intensification to enhance its sustainability, presence of socio-economic co-benefits increase the robustness and sustainability of the intensification or adaptation strategy in question.

Considering these factors, there is need for integrated sustainable adaptation solutions designed to directly and simultaneously address several goals: 1) sustainably increase farm productivity 2) increase climate-resilience and adaptive potential and, 3) stabilize local livelihoods.

1.7 Conservation Agriculture: A Global Impact-Assessment

Conservation Agriculture (CA) is loosely defined as an agro-ecological method of sustainable intensification (Kassam, Derpsch, Friedrich, 2014). CA is largely considered to be a climate-smart agriculture (CSA) cropping practice which simultaneously improves farm productivity and efficiency and adaptive capacity while decreasing environmental degradation. For this reason, CA is a core element of FAO's sustainable crop production intensification strategy (Owenya et al., 2012). While it is common for CA systems to adapt to local conditions, and, by consequence, different authors define CA in different ways (Nyende, 2007), the most general definition of CA provided by the FAO, will be the definition for CA used hereafter for the purposes of this study:

> *"CA is a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment. CA is based on enhancing natural biological processes above and below the ground. Interventions such as mechanical soil tillage are reduced to an absolute minimum, and the use of external inputs such as agrochemicals and nutrients of mineral or organic origin are applied at an optimum level and in a way and quantity that does not interfere with, or disrupt, the biological processes"* (Nyende, 2007).

More specifically, a CA system is defined by simultaneous application of three main principles; 1) minimal soil disturbance, 2) maintenance of permanent soil cover, and 3) use of crop rotation/ intercropping. Benefits from proper application of each practice are as follows:

Principle 1: Minimum soil disturbance

No or minimal soil disturbance is achieved by direct seeding rather than tilling/ ploughing the soil prior to planting (FAO, 2015). Common advantages of minimum tillage are:

- Reduced topsoil erosion by water and wind (Thierfielder & Wall, 2009),
- Long-term fuel, time and labor cost savings (Kassam et al., 2009),
- Reduction of soil compaction and improved hydro-infiltration (Thierfielder & Wall, 2009),
- Soil moisture conservation (Therfielder & Wall, 2009),
- Improved soil organic matter composition (Six et al., 1999),
- Increased yield per unit of fertilizer or manure applied (Rockstrom et al., 2009)

Principle 2: Maintenance of permanent soil cover

Maintenance of permanent soil cover refers to crop residue retention (leaving stems, stalks, shells of crop on field) and/or mulch (organic materials such as decomposing leaves, bark or compost) (FAO, 2015). The purpose of this practice is two-fold: soil enrichment and insulation. Common benefits of continuous soil-cover are as follows:

- Reduced erosion by water and wind (Therfielder & Wall, 2009, Giller et al., 2011),
- Weed suppression (Nichols et al., 2015, Odihambo et al., 2015),
- Improved nutrient cycling (Randriamanantsoa et al., 2011, Lal, 2015, Hobbs, Sayre & Gupta, 2008),
- Improved organic matter accumulation (Lal, 2015),
- Carbon sequestration, although increase of carbon sequestration is highly dependent on soil type and use of mulching (Powlson et al., 2016, Milder et al., 2011, Kimaro et al., 2016)

Principle 3: Use of inter-season crop-rotations or inter-cropping

Crop-rotation is the alternation of different crops in the same field. Commonly experienced dvantages of crop rotation include:

- Improvement of water use (crops with unequal rooting depths will utilize water at different depths (Randriamanantsoa et al., 2011),
- Reduction of pests and diseases: different crops are susceptible to different pest agents and insects; crop rotation can interrupt life and breeding cycles of different insects (Randriamanantsoa et al., 2011),
- Improved fertility and yield: Crops with different rooting patterns utilize nutrients at different soil depths. Crop rotations can, therefore, increase nutrient access for crops.
    - Intercropping with legumes imparts nitrogen fixation benefits, this is highly appropriate in areas where fertilizer is not readily available (Randriamanantsoa et al., 2011)

Per FAO, the economic benefits of CA are labour reduction, increased time savings for farmers (mostly due to removal of the soil preparation burden), reduction of costs from reduced need for fuel and machinery for tilling services, and higher efficiency (more yield for less agronomic input) (FAO, 2015). Various financial analyses of conservation agriculture have also indicated that CA increases net-returns as compared to conventional tillage farming (Knowler & Bradshaw, 2007). A component- specific breakdown of the main agronomic and social CA benefits is depicted below (Fig. 1.8).

CA component ► To achieve ▼	Mulch cover (crop residues, cover-crops, green manures)	No tillage (minimal or no soil disturbance)	Legumes (as crops for fixing nitrogen and supplying plant nutrients)	Crop rotation (for several beneficial purposes)
Simulate 'forest floor' conditions	√	√		
Reduce evaporative loss of moisture from soil surface	√			
Reduce evaporative loss from upper soil layers	√	√		
Minimize oxidation of soil organic matter, CO_2 loss		√		
Minimize compaction by intense rainfall, passage of feet and machinery	√			
Minimize temperature fluctuations at soil surface	√			
Maintain supply of organic matter as substrate for soil biota	√			
Increase and maintain nitrogen levels in root-zone	√	√	√	√
Increase CEC of root-zone	√	√	√	√
Maximize rain infiltration; minimize runoff	√	√		
Minimize soil loss in runoff or wind	√	√		
Maintain natural layering of soil horizons by actions of soil biota	√	√		
Minimize weeds	√	√		√
Increase rate of biomass production	√	√	√	√
Speed soil porosity recuperation by soil biota	√	√	√	√
Reduce labour input		√		
Reduce fuel-energy input		√		
Recycle nutrients	√	√	√	√
Reduce pests and diseases				√
Rebuild damaged soil conditions and dynamics	√	√	√	√

Figure 1.8: Agronomic and social outcomes occurring from full application of CA (Friedrich et al., 2009).

1.7.1 CA System Limitations and Opportunities

CA has steadily gained prominence in diverse agroecological zones across the world (AGRA, 2014). Since its origin in the mid-1930s, a response to the dust-bowls and land degradation in the US, it has come to cover approximately nine percent of total cropped land globally

(Kassam, Derpsch & Friedrich, 2014), with the greatest uptake and cropping success occurring in South America (Fig. 1.9). However, despite CA producing great success and beneficial impact in select regions of the world, it should be noted that effects from CA can vary with different social, economic, and edaphic circumstances (Kimaro et al., 2016), and CA has varying levels of benefits and limitation in different systems. For example, global meta-analyses of yields in CA versus conventional plots revealed CA can result in lowered yields in humid areas without proper drainage techniques (Nyamangara et al., 2014, Plamer, 2007, Giller et al., 2009), because of waterlogging in soils. With reference to crop yield, the technology performs best under rain-fed conditions in dry climates (Pittelkow et al., 2015). Additionally, CA should also not be considered an immediate fix for degraded soils; benefits of CA increase over time (Corbeels et al., 2013), with most benefits being seen after more than one or two years of dedicated practice (Kassam, Friedrich & Pretty, 2009). CA is, therefore, an innovation requiring initial investment of time and resources to see gradual benefit in the farming system.

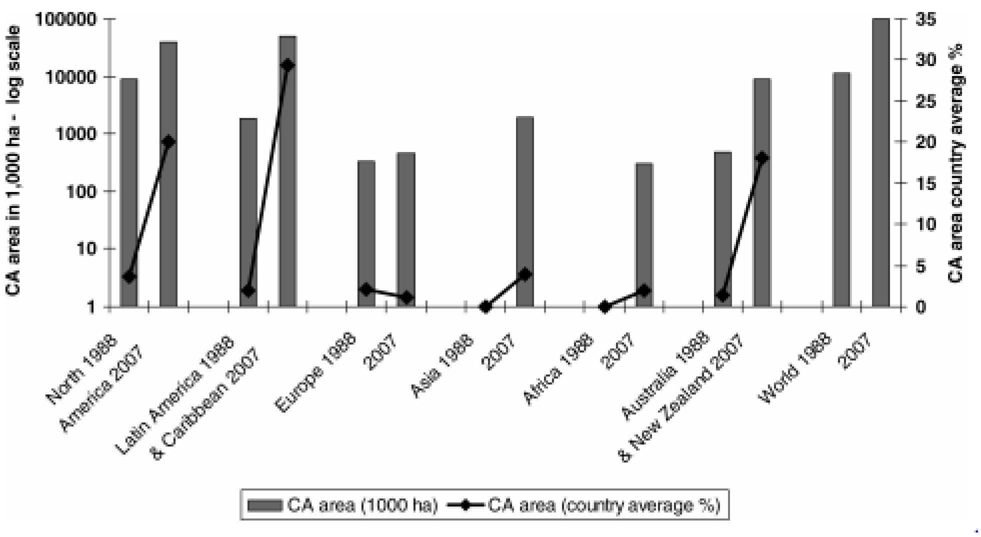


Figure 1.9: Average percentage of land (ha) under CA compared between 1988 and 2007. Only adopting countries of each continent were included in totals (FAO, 2008).

1.8 CA Opportunities in SSA and Kenya

CA has shown great promise in the semi-arid agroecological zone of sub-Saharan eastern Africa (AGRA, 2014). Long-term studies on CA's rain-fed maize production smallholder systems in various arid, rain-fed systems in sub-Saharan Eastern Africa found heightened productivity, water-use efficiency, and labour-use efficiency of CA systems as compared to conventional agriculture, with the greatest positive results coming from full CA treatment (practicing of all 3 principles) and fertilizer application (Thierfelder et al., 2013, Kimaro et al., 2016). Yields, in some cases, were 91 percent higher than conventional plots (Thierfelder et al., 2013). However, despite the potential of CA to heighten the productivity of smallholder maize systems, uptake in SSA has been the slowest of any other continent (Fig. 1.9) due to complex institutional, agronomic and cultural realities (Corbeels et al., 2015).

The Kenya Climate Change Action Plan (2013-2017) identifies CA as a a vital CSA strategy in developing the agricultural sector's climate-resilience, but notes a low degree of adoption (Fig. 1.10); less than one percent of arable land in Kenya was under CA in 2007/8 (Kassam et al., 2009). There have been several key CA projects in Kenya which have worked to upscale the technology to appropriate farming communities to transform smallholder agriculture. One such project was The Conservation Agriculture for Sustainable Agriculture and Rural Development (CA-SARD) project implemented in Laikipia, Kenya, a semi-arid district with majority smallholder agriculture which was experiencing steady declines in crop yield, particularly maize, and challenges with food-security (Fig. 1.12) (Kaumbutho & Kienzle, 2007).

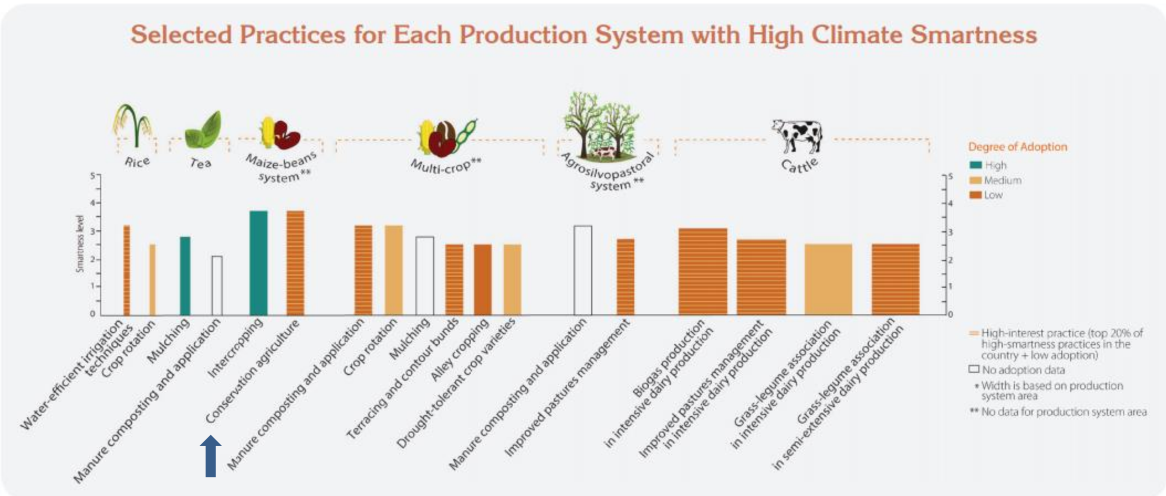
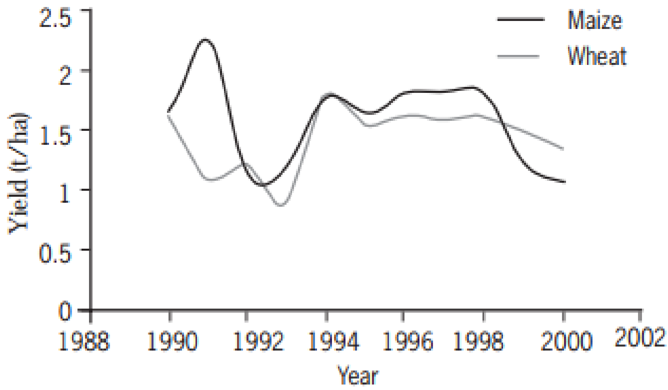


Figure 1.10: Array of CSA practices for each of the significant production systems in Kenya, their degree of adoption in Kenya, and their climate 'smartness' level. This ranges from '1' (having a very low positive impact) to '5' (having a very high positive impact) (Republic of Kenya, 2016)

Figure 1.11: Positioning of Laikipia county in Kenya (Kaumbutho & Kienzle, 2009).

Figure 1.12: Pattern of average maize and wheat production in Laikipia, Kenya from 1988-2002 (Kaumbutho & Kienzle, 2007)



1.8.1 Opportunities and Challenges of CA Uptake in Laikipia County, Kenya

A post project activity case-study: "Conservation Agriculture as Practiced in Kenya: two case-studies" (Kambutho & Kienzle, 2007) was conducted by CIRAD (French Agricultural Research Centre for International Development), FAO, RELMA in ICRAF (Regional Land Management Unit of the World Agroforestry Centre) and ACT (African Conservation Tillage Network) found marked yield increases of main Laikipian crops of up to 200 percent in farms which switched from the conventional methods to CA (Fig. 1.12). Additionally, it was discovered that labour in CA farms was reduced by an average of 30-40 percent (Kambutho & Kienzle, 2007).

Crop type	Crop yield (t/ha)		Yield increase (t/ha)	Percentage increase
	Conservation tillage	Conventional tillage		
Maize (with bean intercrop)	3.3–4.5	1.3–2.2	2.0–2.2	100–150
Wheat	3.3–3.6	1.3–1.8	1.8–2.0	100–150
Potato	12.8	6.4–9.6	3.2–6.4	50–200
Bean (with maize intercrop)	0.6–0.9	0.2–0.4	0.3–0.5	102–155

Figure 1.13: Yield comparison (%) between CA and conventional tillage for major Laikipian Crops (Kambutho & Kienzle, 2007).

1.8.2 Challenges with CA Mechanization

The case-study noted several significant barriers to uptake of CA (Kaumbutho & Kienzle, 2007); the adoption challenge cited as being the most prominent was inadequate access to inputs. The report cited a pivotal lacking input to be equipment and tools enabling the proper mechanization of CA, stating:

> *"The biggest challenge lies with small-scale farmers who aren't able to get the farm inputs needed for conservation agriculture. For instance, a sprayer is needed to control weeds without disturbing the soil. The area of land farmed determines the capacity of the sprayer to be used. The larger the amount of land being farmed, greater the likelihood a farmer will be motivated to invest in equipment to ensure the quality and quantity of the spray. Small-scale farmers do not have options since they can barely afford even a knapsack sprayer"* (Kaumbutho & Kienzle, 2007).

Agricultural mechanization (AM) is defined by the FAO as "All levels of farming and processing technologies, from simple and basic hand tools to more sophisticated and motorized equipment" (FAO, 2016). Power categorizations of mechanization are manual, animal, and motorized (FAO, 2016); this paper will utilize this definition of mechanization as well as being inclusive of each power-type of mechanization (Sims, 2016a).

Machines and tools are considered crucial inputs for sustainable intensification and the growth and development of the agricultural sector because of increased capacity and efficiency of farming operations (Baudron et al., 2015). Mechanization supports lowered production costs (Fig. 1.13), minimized drudgery, increased efficiency, creation of quality employment in rural areas, and enables movement from 'subsistence' to 'commercial' agriculture, as well as making agriculture more attractive for women and youth (Sims, Hilme & Kienzle, 2016). It also has the potential to decrease the possibility of low yields because of increased cropping intensity, well-timed planting, weed control, and crop harvesting (Sims, Hilme & Kienzle, 2016, Baudron *et al*., 2015).

Aspects of weeding costs	Sorghum		Groundnuts	
	DAP Weeding	Hand Weeding	DAP Weeding	Hand Weeding
Weeding (h/ha)	34.7	157.8	31.8	73.2
Cost of weeding (USD)	6.12	27.85	8.07	18.07
Return per day of weeding labor (USD)	11.40	2.19	135.78	18.42
Weeding as % of total costs (%)	13.2	51.3	7.7	21.5

Figure 1.14: Draught animal power (DAP) as compared to hand weeding labour costs in Uganda (Sims & Kienzle, 2016)

As previously stated, the mechanization level in SSA is the lowest in the world (AGRA, 2014), with approximately 70 percent of operations being driven by manual labour (Sims and Kienzle, 2015). While in other continents and areas of the world, AM has experienced a general upward trend, in SSA, it has decreased (Fig. 1.14) (Sims, Hilme & Kienzle, 2016).

Sustainable agricultural mechanisation (SAM), which “supports the development of food supply chains through improved agricultural practices for increased production and enhanced food security” (FAO, 2017) is increasingly pertinent to Kenya’s agricultural transformation. As is patterned in wider SSA, level of mechanization in Kenya is low (Fig. 1.15), especially among smallholder farmers living below the poverty line (Fig. 1.16). This is due to issues with smallholder finance, availability, lack of capacity, and constraints within the private sector (Sims, Hilme & Kienzle, 2016).

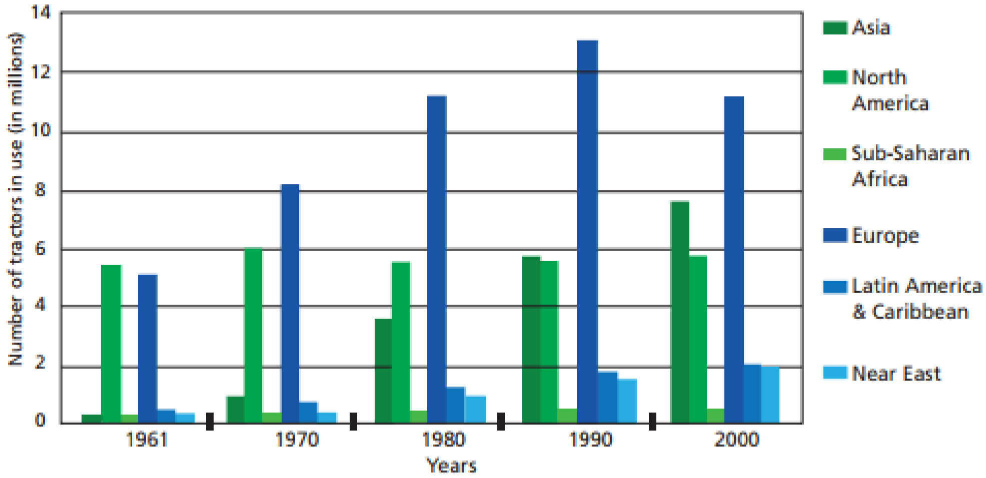
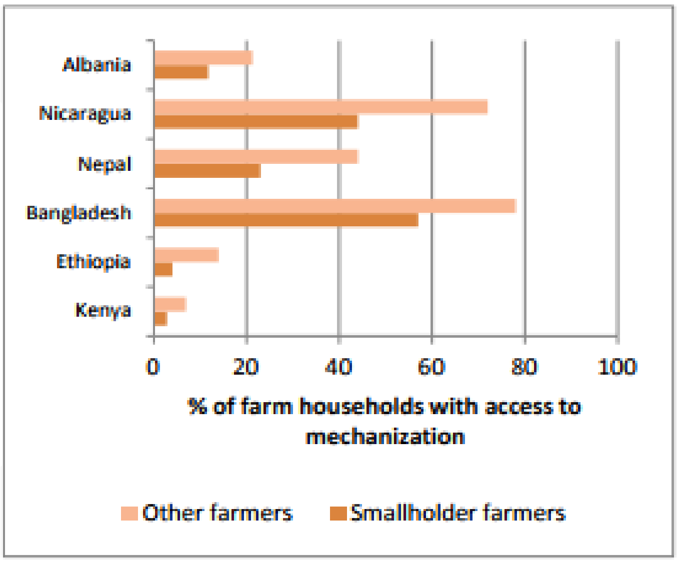


Figure 1.15: Tractor use by region (FAO, 2008)

Figure 1.16: Percent of farm households with access to mechanization (Rapsomanikis G., 2015).



Considering the contributory potential of AM in sustainable intensification, AM remains an unmined opportunity for boosting productivity and food-security in SSA; the FAO has described AM as the "neglected waif" of rural and agricultural advancement (FAO, 2013). Sustainable agricultural mechanization is an approach to mechanization of sustainable agricultural systems, and incorporates incorporates food supply chain development (FAO, 2016). FAO's "Save and Grow" paradigm advocates for the mechanization of eco-agriculture sustainable intensification systems such as CA, as this would deliver a range of productivity, socioeconomic and environmental benefits in parallel improving climate resilience (Sims, Hilme & Kienzle, 2016).

If CA is to be upscaled in a way that delivers maximum benefit to farmers, and encourages uptake, strategies for adequate mechanization of CA in smallholders will need to be developed. CA technologies are key inputs for a well-functioning CA system (Sims et al., 2015). Tools and equipment utilized in conservation agriculture can be broadly sorted into minimum tillage equipment (rippers, sub-soilers, and chisel ploughs), direct seeding equipment (manual, animal drawn or motorized jab planter, planting stick) and cover crop and weed management equipment (manual shallow weeder, animal-drawn light weeder, backpack herbicide sprayer, draft animal pulled sprayer) (Fig. 1.17).

Figure 1.17: Non-extensive examples of CA equipment: A) Manual-hoe digging planting basins, B) Animal-drawn direct seeder C) Direct seeding utilizing a jab-planter (Giller et al., 2015), D) Tractor drawn combined ripper, planter, fertilizer E)Manual direct seeding with pointed stick, F) No-till crop sowing by means of a disc seeder with satellite direction with 2 cm precision to sow between the rows of preceding crop residue G)Ripped field prepared for planting (FAO, 2013)

As an overall trend, mechanization of CA in SSA is lower than that of conventional agriculture, owing to its current status as a niche innovation; there are several associated issues of lack of critical mass and demand, lack of reliable supply chain, and inability of farmers to procure CA equipment and tools, even for basic CA hand tools in some regions (Sims et al., 2015). While previous case studies have been conducted on CA in Kenya, and have referred to mechanization within their scopes (Kaumbotho & Kienzle, 2007, Zaal, 2015, Kahan, Bymolt & Zaal, 2017), particulars of CA barriers to adoption and SAM bottlenecks are generated from national, regional and local level realities, and require unique investigation for contextualised understanding.

1.9 Study Outline

This paper, through the 'case study' methodology, will research barriers to the SAM of CA in smallholder maize farmers in Laikipia County, Kenya. Results of the case-study, as well as the findings from cross-sectional review of other case-studies, will support larger conclusions about the opportunities and challenges of SAM of CA in smallholder Kenyan farmers. Finally, recommendations to alleviate challenges and realise opportunities found by the case-study will be supported by information from semi-structured interviews with various stakeholders of CA, as well as a review of policies around CA in Laikipia and wider Kenya.

1.10 Research Rationale

The importance of mechanization of SSA is increasingly recognized by international and pan-African actors as a central component to the achievement of multiple imperatives. The Framework for Sustainable Mechanization drafted by the African Union Commission (AUC) and FAO is considered a critical step towards the AU Malboro Declaration (2014) to "End Hunger" in African Union (AU) member states by 2025 (FAO, 2017). AU member states are pressed by AUC and FAO to employ swift adoption of the framework for the purposes of agricultural transformation in SSA, and redressing persistent yield-gaps/ lack of intensification of smallholder farms (FAO, 2017).

Extra to striving for improved efficiency and productivity, environmental sustainability is another aspect which must be considered in a robust agricultural transformation strategy.

Without intervention, the rapidly increasing populations of SSA will face dire challenges regarding food-procurement and degraded resource-bases resulting from unsustainable land-management. Without adaptive measures, climate change effects will aggravate these already difficult realities, and will serve to widen inequalities between the resource-poor and resource-rich. A negative feedback loop between poverty and resource degradation is often patterned in these circumstances; further degradation can result in forced migrations, resource conflicts and pervasive undernourishment (Leach, Mearns & Scoons, 1999) The urgency for transition to increasingly sustainable land-use concerns the interests of both current and future generations. Thusly, mechanization should be prioritized in systems such as CA, which have reduced negative environmental impact and improved yields for smallholder systems (conferring greater adaptive capacity), as part of both upscaling CA, and integrating multiple development goals to achieve a harmonized approach.

Considering these factors, SAM of CA is a triple win in its value-adding potential to all three dimensions of sustainable food production: social, economic, and environmental. In terms of the United Nations Sustainable Development Goals (SDGs), effective SAM of CA can simultaneously further multiple goals: SDG 1: No Poverty, SDG 2: Zero-Hunger, SDG 5: Gender Equality SDG 9: Industry, Innovation and Infrastructure SDG 13: Climate Action and SDG 15: Life on Land. Examination of the particulars of CA SAM in Kenya has been a recent topic of interest to multiple stakeholders, however, no case-studies with a focus on CA SAM in Laikipia have yet been conducted.

1.11 Research Questions

The aim of the research questions of this study is to investigate the status of CA mechanization in Laikipia, Kenya contextualized within the larger scope of Kenya-wide agricultural mechanization. The study findings will be utilized in development of targeted recommendations to expedite the SAM of CA in Laikipia, and wider Kenya. The research questions are as follows:

1) Was mechanization a major barrier to uptake for the smallholder farmer participants in the African Conservation Tillage Network's (ACT) Conservation Agriculture for Food Security (CA4FS) Project? What situational factors contributing to the mechanization experience of the participants?

2) How sustainable are present mechanization realities?
3) What are the larger trends of CA mechanization in Kenya?
4) What changes can be made on national, regional, and project levels to facilitate greater SAM of CA?

Chapter 2: Methodology

2.1 Overview

In summary, the research design for formulating policy recommendations is classified as "case study", with qualitative data being derived from semi-structured interview responses, Per Yin (2003) a case-study should be deliberated for the research methodology when "(a) the focus of the study is to answer "how" and "why" questions; (b) you cannot manipulate the behaviour of those involved in the study; (c) you want to cover contextual conditions because you believe they are relevant to the phenomenon under study; or (d) the boundaries are not clear between the phenomenon and context" (Baxter et al., 2008; Yin, 2003). CA mechanisation, in different socioeconomic, geographical, and political contexts, has been implemented and adopted with varying degrees of effectiveness (FAO, 2003); therefore, site-specific contextual conditions are imperative to understanding the realities of CA interventions and projects.

More specifically, a "multiple-case study" is appropriate, as observing congruencies and divergences between cases brings deeper understanding of barriers and struggles experienced across a variety of contexts (Yin, 2003). However, due to limitations of various resources, namely time, a single case-study was conducted, though other findings from other case-studies were used for cross-comparative purposes.

The research methodology was comprised of six parts: 1) literature review, 2) desk-review of ACT's Conservation Agriculture for Food-Security (CA4FS) project design 3) field-visit to both 'mother demos' and 'baby-demos' of the Laikipia District, with an attempt to reach equal numbers of CA adopters and non-adopters, and conduction of semi-structured interviews with farmers 4) semi-structured interviews with other identified stakeholders (government, academic, private, NGO's/ international donor agencies) 5) assessment of the larger context of CA in Kenya, including barriers to implementation 6) formulation of recommendations.

A condensed summary of each research component has been included below:

2.2 Research Components

2.2.1 Literature review

Review of peer-reviewed literature sources, national/regional policy documents, and case studies were used to assess the realities of AM for smallholder Kenyan maize farmers practicing CA, with particular emphasis placed on observed bottlenecks to SAM of CA in Kenya, SSA and regions across the world. Case-studies from Sub-Saharan Africa were mostly studied, however, case-studies and policy documents from parts of the world (such as Bangladesh) where CA has high uptake and levels of mechanisation were used as supplementary sources for cross- comparison and recommendation development.

2.2.2 Review of ACT's CA4FS Project

A review of ACT's Conservation Agriculture for Food Security (CA4FS) project's experimental protocols and outcomes was used to supplement my case-study design, identify stakeholders, and develop appropriate interview questions and soil sampling protocols. The aspects of the project used for these purposes are as follows:

CA4FS Aim and Goal:

ACT's CA4FS project aimed to "improve food and income security by building the resilience of smallholder farmers in Machakos and Laikipia counties of Kenya through enhancing the adoption of conservation agriculture practices." (ACT, 2017). The project activities, running from 2013-2016, took place in the Laikipia and Machakos counties of Kenya.

CA4FS Objectives:

The objectives of the CA4FS project were multi-fold, they are as follows (ACT, 2017):

1 "To evaluate and identify cover crop options for conservation agriculture";

2 "To increase awareness of conservation agriculture among smallholder farmers and extension staff in Machakos and Laikipia counties through wide scale demonstration";

3 "To improve access to information and communication products on conservation agriculture for practitioners including policy makers";

4 "To improve smallholder farmers' access to input and output markets".

CA4FS Experimental Design:

The Mother-Baby trial design (Snapp, 2002) was applied to 230 plots, all classified as smallholder, in the Laikipia and Machakos counties. The cereal crops analysed are *Zea mays* and *Sorghum bicolor* (sorghum); the cover crops utilized were *Lablab purpureus* (dolichos) and *Cajanus cajan* (pigeon peas).

The "mother demo" (Snapp, 2002) plots received all five CA treatments plus a control (conventional practice), while the "baby demos" received only two treatments plus a control. Treatments applied were as such:

T1 Farmer practice**:** Conventional ploughing (ox or tractor), no residue retained
T2 Conventional plough practice with fertilizer, no residue retention
T3 Minimum tillage with no fertilizer and no residue retention
T4 Minimum tillage with fertilizer and no residue retention
T5 Minimum tillage, without fertilizer, with residue retention
T6 Minimum tillage with fertilizer and with residue retention

At the start of the project, inputs provided to project participants were seeds and nitrogen fertilizer.

Quantitative, baseline data of maize/sorghum yield, soil properties (pH, organic carbon, total nitrogen/ potassium, extractable phosphorous, and exchangeable bases), rainfall, and various socio-economic metrics of farmers (labour, input price, gross margins, benefit/ cost ratio) were collected from each of the "mother demo" plots; post project data collection for the same metrics was conducted. At the closure of the project activities, the farmer determined which treatment was the most appropriate for their farm. End of project data was collected to be assessed against the baseline data, but is still undergoing compilation.

CA4FS Scope:

Thirty "mother-demo" plots and 200 "baby demo" plots across both counties, with 12 and 18 plots in the Laikipia and Machakos counties respectively; conducted for each of the "mother demo" plots. Both "mother demo" and "baby demo" plots were analysed by the case-study. Each mother demo site in Laikipia was visited, while baby-demo sites were chosen without criterion, as there was not socioeconomic, gender, education-level or income data available for the baby-demo farmer group. It was the aim of the case study, however, to reach equal numbers of CA adopters and non-adopters.

2.2.3 Field visit to Laikipian mother-demos: interviews

In June, and July, 2017, two field visits, the first to the 12 mother-demo sites, and the second to 12 baby-demo sites in the Laikipia East and Laikipia Central sub-counties took place for the purpose of conducting interviews. The farmers, along with other stakeholders interviewed in Laikipia (FAO extension-officer, local fabricator, and Laikipia Department of Agriculture, Livestock and Fisheries representative) were interviewed using a semi-structured interviewing method.

Per Bernard (1988), a semi-structured interview is appropriate when one “won't get more than one chance to interview someone” and when the topic of interest is centred around the participants’ experiences. Given that situational factors on each individual, family, farm, and community can vary widely, and these situational factors heavily influence on uptake and outcomes (FAO, 2003), the semi-structured method was determined to be the most appropriate for the purposes of this case study.

An open-ended questionnaire (Appendix I), containing questions developed from the literature and case-study review, was followed to prevent the interview from deviating from key areas of interest. The interview was preceded by an explanation of the research and participants’ rights. Written or oral consent to the explicated interview conditions was obtained prior to interview conduction. Although all participants spoke a degree of English, A Swahili- English translator was present to avoid confusion or misunderstandings with more technical language.

The qualitative data gained from the interviews was audio-recorded, then later reviewed to determine patterns and relationships.

2.2.4 Interviews with other stakeholder groups:

CA initiatives and projects in general, including CA4FS, involve a variety of stakeholders; the stakeholders oftentimes heavily influence the outcomes and uptake of CA. The conclusion of the 'semi- structured interview' being the most appropriate method for interviewing other stakeholder groups closely followed the reasoning for the farmer group.

A semi-structured questionnaire was developed for each selected stakeholder interviewee. As with the farmer group, prior to the interview, the participant was informed of his/her rights, and gave oral/ written consent before the commencement of the interview. Each interview was audio-recorded, and later analysed. After review of multiple CA initiatives across Kenya, Tanzania, Ethiopia and Brazil, the stakeholder sectors identified were 1) government/policy 2) academic/research 3) private-sector/market 4) non-governmental organisations (NGOs) and international donor-agencies.

More specific CA SAM stakeholder groups and organizations of Laikipia and Kenya found by desk-research and recommendations from ACT are summarized below:

1) **Government/ policy stakeholders:** Ministry of Agriculture (MOA), Ministry of Environment, Laikipia Municipal Government, Agricultural Mechanization Stations (AMS).
2) **Research:** University of Nairobi, Maseno University and Masinde Muliro University of Science and Technology (MMUST), Kenya Agricultural Research Institute (KARI), Kenya Network for Dissemination of Agricultural Technologies (KENDAT)
3) **Private Sector:** Agrimech Hub Ltd., small-scale local fabricators in Laikipia, large-scale fabricators in Nairobi
4) **NGO's/ International donor agencies:** FAO, World Agroforestry Center (ICRAF) Regional Land Management Unit, International Maize and Wheat Improvement Center (CIMMYT), African Green Revolution Alliance (AGRA), Africa Conservation Tillage Network (ACTN)

2.2.5 Assessment of barriers to implementation of SAM of CA

Results of interviews were cross-compared with the findings and results of three case-studies. Primary case studies analysed were those done in Kenya (Kaumbutho & Kienzle, 2007), Zambia (Sims, Breen & Luchen, 2015), and Bangladesh (Akteruzzaman, Jahan & Haque, 2014). CA mechanization in Zambia and Bangladesh were chosen for cross comparison because of their commonality in possessing developing economics, smallholder dominance, and small, scattered farms (Diao et al., 2012). Zambia and Kenya are both still in transitional stages of mechanizing CA, but Zambia has higher uptake owing to wide institutional and government support of CA (Sims, Breen & Luchen., 2015), while Bangladesh has effectively mechanized its CA supply-chain and operations (Akteruzzaman, Jahan & Haque, 2014).

2.2.6 Recommendations:

Policy recommendations were developed with respect to 1) Interviews of stakeholders (participants, institutional, political, NGO/UN and private) 2) Analysis of case-studies of other CA projects 3) valuation of larger policy and investment prospects for CA SAM in national and international arenas.

Chapter 3: Results

A total of 24 farmers and six other stakeholders from the research, NGO/ international organization, government and private sectors were interviewed; in addition, one farmer-self-help group session was attended. Details of interviewees are given below:

Title:	Name:	Company/ Organisation:	Position/ Stakeholder group:
Mr.	Burii, David	Mwireri Engineering	Owner, private fabrication company
N/A	Ebeneza Self Help Group	N/A	Farmer self-help group
Ms.	Gashoki, Alice	N/A	Mother-demo farmer, CA adopter
Mr.	Gathuki, Josphat	N/A	Baby-demo farmer, CA adopter
Mr.	Githaiga, Simon	N/A	Baby-demo farmer, CA adopter
Dr./ Eng.	Kaumbutho, Pascal	Agri-mech Kenya Network for Dissemination of Agricultural Technologies (Kendat)	Chairman, Agri-mech CEO, Kendat
Ms.	Kimani, Alice	N/A	Baby-demo farmer, CA adopter
Mr.	Kinuya Gakenge, Silvester	N/A	Mother-demo farmer, CA adopter
Ms.	Mainia, Elisabeth	N/A	Mother-demo farmer, CA non-adopter
Mr.	Mathai, Arthur	County Environment and Land Development Officer	Laikipia county government
Ms.	Migwi, Grace	N/A	Mother-demo farmer, CA adopter
Eng.	Mkomwa, Saidi	African Conservation Tillage Network (ACT)	Director, Non-governmental organization (NGO)
Mr.	Muchangi, Moses	Food and Agriculture Organisation of the United Nations	Extension officer, international organisation
Ms.	Mumbi, Mary	N/A	Baby-demo farmer, CA adopter
Ms.	Muthoni, Jennifer	N/A	Baby-demo farmer, CA adopter
Dr.	Mwangi, Hortensia	Kenya Agricultural Research Institute, National	Weed-control research scientist

		Agricultural Research Laboratories	
Ms.	Njoora, Nancy	N/A	Baby-demo farmer, CA non-adopter
Mr.	Ngure, Peter	N/A	Mother-demo farmer, CA adopter
Mr.	Nguyo, Ephraim	N/A	Baby-demo farmer, CA adopter
Ms.	Njeri, Ann	N/A	Baby-demo farmer, CA non-adopter
Mr.	Njeru, Simon	FEMO Works Ltd.	Owner, private fabricator
Ms.	Nyangari, Elisabeth	N/A	Mother-demo farmer, CA non-adopter
Ms.	Wambogo, Joyce	N/A	Baby-demo farmer, CA adopter
Ms.	Wambui, Agnes	N/A	Baby-demo farmer, CA adopter
Ms.	Wameru Ann	N/A	Mother-demo farmer, CA adopter
Ms.	Wamuyu, Hannah	N/A	Baby-demo farmer, CA adopter
Ms.	Wangoi, Margaret	N/A	Mother-demo farmer, CA adopter
Ms.	Wanjiku, Mary	N/A	Mother-demo farmer, CA adopter
Ms.	Wanjiku, Rosemary	N/A	Baby-demo farmer, CA adopter
Ms.	Wanjiru, Angelica	N/A	Mother-demo farmer, CA adopter
Ms.	Warimu Riri, Grace	N/A	Baby-demo farmer, CA non-adopter
Mr.	Waweru Mumbiko, Rafael	N/A	Mother-demo farmer, CA adopter

Table 3.1: Case-study interviewees

The National Agricultural Mechanization Strategy – MAMS (1995) and Strategy for Revitalizing Agriculture (2004-2014) identifies low levels of mechanization as one of the main causes of low agricultural productivity (Alila & Atieno, 2006). It is further specified that the three main causes of low utilization of mechanization to be due to 1) Lack of finance available to farmers 2) Inadequate mechanization extension services 3) Inadequate access to mechanization technologies. Each of these barriers appeared in the case-study interviews with Laikipian CA adopters/ non-adopters, extension officers, private entities, and NGO’s.

A summary of key farmer response types is included in Table 3.2. Relevant quotes and ideas gleaned from non-farmer stakeholder groups are included in the main body of the text. Full transcripts of any of the interviews is available from the author upon request.

Interview Question:	Response Distribution (totaled out of 24):
Have you continued to practice CA post project?	Yes: 19 (79%) No: 5 (21%)
Did you experience increased yields under CA?	Yes: 24 (100%) No: 0 (0%)
Did you experience increase profit while practicing CA?	Yes: 24 (100%) No: 0 (0%)
Do you use service providers? If so, which type?	Agrimech Hub: 3 (12%) Nomadic: 7 (29%) Another farmer: 2 (~1%) AMS: 0 (0%) Do not use service providers: 14 (58%)
How were you connected to service providers?	Local extension Officer: 8 (33%) Word of mouth: 7 (29%) Not connected/ didn't know of CA service providers: 9 (38%)
What are the main challenges that you experienced with CA?	Mechanization challenges: 8 (33%) Other challenges: 9 (38%) No challenges: 7 (29%)
Were the new tools/ equipment required for CA technology been affordable?	Yes: 16 (66%) No: 8 (33%)
From where did you procure the new tools?	Local artisan adapted CA tool from old, conventional tools: 24 (100%)
When you are/were practicing CA, was there equipment/ services which you need(ed) but couldn't access?	Yes: 10 (41%) No: 14 (59%)
What has prevented the acquisition of those tools?	Too expensive: 6 (55%) Unable to procure/ don't know where to find them: 5 (45%)
Have you or your farmer group received equipment, or had access to subsidized equipment?	Yes: 0 (0%) No: 24 (100%)

Table 3.2: Key responses of farmers interviewed

3.1 Lack of finance available to farmers

Lack of finance is one of the principal barriers that must be addressed with smallholder farmers in CA, as there are considerable investment costs accompanying procurement of CA technology (Friedrich & Kienzle, 2007). It was found in the case-study that low-income of most subsistence, small-scale farmers makes personal purchase of mechanical inputs financially risky or unfeasible, especially in farmers with unsecured land tenure. Even if farmers' perception of mechanical inputs shifts to consideration of purchase of mechanised equipment as a worthy investment, smallholder farmers securing the necessary credit with which to do so from reputable sources (such as banks) has been a persistent barrier (FAO, 2015).

Stakeholder interviews and surveys identified three primary routes to technology access for smallholder CA farmers in Laikipia found by the case study: 1) farmer-purchase of own equipment 2) service-providers- via 'mobile' service providers, the local mechanization hub, or other local CA farmers (often large- scale) 3) shared purchase or use of donated equipment by farmer groups. In Laikipia county, 50.5% of the total population lives below poverty line compared to the national average of 47.2%; (Office of the Controller of Budget, 2017). Smallholder farmers in Laikipia are one the largest demographic living in poverty (County L., 2012). Personal purchase of inputs, especially of costlier animal-drawn or diesel mechanical inputs (Fig. 3.1), has inbuilt financial risk for farmers, especially being that CA is a system which begins to show increased financial return after several years of practice. It was a general observation of the case-study that this reality brings uncertainty for farmers, especially under drought conditions and variable harvests, which is a common issue in the semi-arid climate of Laikipia.

Equipment	Price (USD)
Jab planter for seed and fertilizer (Fitarelli)	40
Animal-drawn, single-line, long-beam no-till planter and fertilizer (Fitarelli)	500
Tractor-mounted 3-row, no-till planter and fertilizer (Fitarelli)	7000
Animal-drawn 2-row no-till planter and fertilizer (also adaptable to 2WTs) (Fitarelli)	2600
Tractor-mounted 5-row no-till planter and fertilizer (Fitarelli)	10,000
Chinese-made 10 hp 2WT	1000

Figure 3.1: Prices of equipment in their country of manufacture (Sims and Kienzle et al., 2015)

One hundred percent of farmers surveyed in the study, even non-adopters, perceived financial benefits of practicing CA, with the main contributing factor being heightened yields and greater profit (Table 3.2), but personal purchase of diesel and animal drawn machinery was not perceived as affordable, despite increased profit. Although all CA adopting farmers surveyed owned, at minimum, the hand ripper and shallow weeder, two farmers cited difficulty procuring funds for the purchase of additional hand rippers and shallow weeders—opening the possibility of shared labour on the farm. The remaining 22 farmers cited basic CA hand-tools (shallow weeder, ripper) as being affordable, as the tools were unanimously acquired through local artisans converting conventional hand tools, such as the hand-hoe, to CA tools. The manual jab-planter, cited by 6 farmers as having great potential for drudgery reduction and increased planting precision, was considered unaffordable by all farmers who indicated want for a jab-planter. Ms. Nancy Njoora, a CA non-adopter cited drudgerous planting and lack of access to a jab-planter (due to insufficient funding) as the main reason for abandoning CA (Ms. Nancy Njoora, personal interview July 21, 2017).

3.2 Inadequate mechanization extension services

Extension services enable farmers to access machines and services through contract-based work, thereby circumventing the overhead costs associated with purchasing machinery themselves; this is an especially attractive option for smallholders aiming to reduce cost of production.

3.2.1 Chosen farm-power source

A majority of the farmers (58 percent) undertake CA operations manually; the reasoning was either: a) that CA is not labour intensive because of removal of the need to plough, and can be done by hand, or b) that service provision was not available or inadequate (e.g. poorly calibrated machines, unreliability). All respondents with the latter rationale said they would use services if they were affordable and available. Agnes Wambui, a CA adopter said that services are not available in the area and that it affects surrounding farmers' perception of CA "Other farmers see hand ripping and think CA is tedious. If there was more mechanisation, CA would be seen as much more viable" (Ms. Agnes Wambui 2017, personal interview, July 20, 2017). A large group of farmers interviewed (38 percent) were not aware of local service providers offering CA service provision. Of the farmers who knew of local CA service providers, a majority were connected to the providers by their local extension officer (53 percent), while the remainder (47 percent) were connected by word of mouth.

3.2.2 Availability/ quality of various forms of services

The remaining 42 percent of the farmers surveyed said they utilized CA services regularly, or that they used CA services for a limited number of seasons. The three farmers who used mobile service providers in previous seasons but returned to manual labour all cited reliability and/ or quality of service as their reason for abandoning mobile service provision. Farmers who used the Agrimech hub in past seasons, but stopped, cited changes in finance, and/or lack of available machines during peak demand times such as planting season. Moses Muchangi, an FAO extension officer in Laikipia, stated in an interview: “Extension services cannot cover demand; the services are not available. There are still a big number of people demanding conventional services- this is reducing, but service providers are reluctant to buy the new equipment- also the service providers are not yet properly trained. Training for them is marked for the end of July” (Mr. Moses Muchangi 2017, personal interview, June 20, 2017). Similarly, the Ebeneza Self-Help Group members stated “We fear that there won’t be enough machines to go around from the mechanization hub… we want to encourage young people to become service providers so there will be more available” (Ebeneza Self Help group 2017, personal interview, July 22, 2017).

3.2.3 Public vs. private service provision

As noted in the interview with Dr. Pascal Kaumbutho, (KENDAT chairman) as well as generally observed in the case-study, public-sector headed mechanization models have taken precedence across Kenya in the form of 24 Agriculture Mechanization Stations (AMS) supported by the Kenya Ministry of Agriculture offering services for the agriculture sector. Poor organization and limited funding of the hubs, have, however, left the AMS in short supply of functioning machines and, consequentially, limited usage by surrounding farms; farmers surveyed also cited long waits and tedious payment processes as reasons for searching elsewhere for services. Alternative models for sustainable mechanization are, therefore, under exploration- especially models integrating the private sector, as private sector involvement has the potential to stabilize supply and grow the labour market. Laikipia county is host to the Agrimech Africa Ltd. mechanization hub: the first private mechanization business model of its kind in Kenya. Its aim is to be a ‘one-stop shop’ offering mechanization services, equipment production/ training, and value addition/ marketing services (Dr. Pascal Kaumbutho 2017, personal interview, July 18 2017). The presence of CA projects in Laikipia has caused the hub to offer both conventional and CA services and machineries at rates comparable to those of mobile service providers (Dr. Pascal Kaumbutho 2017, personal interview, July 18 2017).

The Agrimech hub, opened in 2016, has steadily gained popularity because of timely services and well-calibrated machines (Dr. Pascal Kaumbutho July 18, 2017), personal interview communication, July 18 2017). However, per responses from farmers interviewed in the case study, the hub has not yet recieved uniform exposure in the surrounding community. Over half of farmers surveyed were not aware of the hub, even if access to services was desired. For example, Ann Njeri, a CA non-adopter stated in an interview she considered the challenge she faced with CA to be getting services. She was told by the local extension officer in 2014 that she would receive ripping services from a mobile service provider, but that the service provider never came. Although the necessary tools were available, she considered the manual reaping “too labour intensive”, and left CA. She was not aware of the Agrimech Hub, although her farm was less than 30 kilometres away. (Ms. Ann Ngeri 2017, personal interview, July 21, 2017).

Farmers further afield from the mechanization hub whom knew about the hub cited the cost for transit fuel (fueling the machine from the mechanization hub to the farm) as a financial barrier to using the services. Mr. Ephiram Nguyo, a CA adopter, said transit makes the Agrimech services unaffordable unless the cost is split between CA group members and services are done in aggregation, but that such organization between farmers is difficult (Mr. Ephiram Nguyo, personal interview, July 20, 2017).

An important factor to note is that the CA service provision problems found in the case study are not limited to Laikipia; conversely, levels of CA mechanization in Laikipia are comparatively advanced. While Laikipia has seen recent growth and diversification for CA services, mainly due to presence of CA projects, the reality varies between counties. Eg. Saidi Mkomwa, Director of ACT, said “in other counties, service providers don’t exist- only in Laikipia and Burgone” (Eg. Saidi Mkomwa, July 24, 2017, interview).

3.3 Inadequate access to mechanization technologies

3.3.1 Local demand and procurement

It was found by the case-study that the beginning stages of CA mecahnisation in Laikipia is characterized by the common problem of the 'vicious cycle of mechanization' pattern; this is defined as: "…A chicken-and-egg situation is created where the supply sector does not offer certain inputs because there is no market for them, but the farmers are also not demanding the items because they are not being offered" (Friedrich & Kassam, 2009). Several farmers indicated relative ease of procuring CA equipment in recent years, a marked improvement from the initial adoption seasons. Mr. Nguyo stated: "Our CA tools are made from metal-work requests. In the past, it was not so easy to find. Artisans didn't know what we were asking for in the beginning… now it is easier, we can find what we want" (Ephiram Nguyo 2017, personal communication, July 20, 2017). Because of CA's sustained presence in Laikipia, local fabricators and agri-equipment suppliers have ready-made stocks of basic CA hand-tools (David Burii 2017, personal interview, July 18, 2017); because of local demand, Mr. David Burii, a local fabricator in Laikipia, is planning on beginning to sell jab planters from his shop alongside hand reapers and weeders if he can get the appropriate materials (David Burii 2017, personal interview, July 18, 2017). This is significant, being that the jab planter was the most commonly cited piece of equipment among the 41 percent of farmers whom said there were tools they needed, but couldn't access.

3.3.2 Capacity-building

Historically, there has been little focus on involving local dealers or fabricators in capacity building efforts for local CA fabrication markets (Eg. Saidi Mkomwa 2017, personal interview, July 24, 2017) There was an observed lack of support for local CA equipment fabricators in Laikipia in terms of facilitated network connections and training packages for quality tool fabrication. While the increase in demand for CA products in Laikipia has created interest from the private sector, without training or certification, this resulted in tools of differential quality and design, which can have a knock-on effect of weakening the local market because "the good quality tools are imported, there are only market spaces for those tools" (Eng. Saidi Mkomwa, July 24, 2017, interview). In the opinion of Mr. David Burii, despite presence of multiple CA projects in the region, training packages not being included for local fabricators created a large gap between fabricators' quality of CA equipment. "Producing quality equipment requires training…it was easy to obtain the materials, but I needed to go to Nairobi to find parts and make connections with the part providers… in the beginning I didn't know what I was making, and it was difficult to find customers" (Mr. David Burii, July 18 2017, interview). While Mr. David Burii stated the situation has improved as more farmers have adopted CA in the area, that he cannot make some pieces of equipment, such as jab-planters, due to lack of necessary materials, and his inability to fund a trip to Nairobi to procure them.

As compared with Laikipia, it was found in the case study that larger CA equipment fabricators in Nairobi faced greater barriers to profit in producing CA equipment because of the lack of demand around Nairobi, intermittent nature of CA projects, and a lack of facilitated distributional network to sell products in counties with CA equipment demand. Simon Ngeru, founder and CEO of Femo Works fabrication in Nairobi cites lack of demand as the principal cause for the lack of in-country fabrication. "it's a question of market and volume- I'm doing it (CA input fabrication) because I'm curious- but in the end, I am in a business… (CA) projects are on and off; a stable network has to be developed" (Mr. Simon Ngeru 2017, personal interview, July 14, 2017).

3.3.3 Importation and local fabrication conflicts:

Thus far, larger CA equipment in Kenya have been largely fabricated abroad in Brazil, India, Bangladesh and China, and imported (Sims & Kienzle, 2015), though in recent years there is growing interest from the local private sector in Kenya in manufacturing CA implements such as tractor attachments (Kendat, 2016). Generally, imported machinery can be more expensive and sub-ideal for local conditions, as machineries and tools should be designed for climate, soil characteristics, agricultural products, etc. of the system within which they will operate. (Sims & Kienzle, 2015).

Eg. Mkomwa stated that the current taxation regime in Kenya "discourages local production (of equipment), as imported machinery does not face a tax, but imported fabrication materials do" (Eg. Saidi Mkomwa, personal interview, July 24, 2017). Similarly, Mr. Ngeru said, "imports are cheaper than local fabrications" (Mr. Simon Ngeru, interview, July 15, 2017). Raw material imports, such as steel and machinery parts, were found to face high duties, and decrease accessibility for local artisans and manufacturers; this is exacerbated by the lack of duty on imported machinery (Dr. Pascal Kaumbutho 2017, personal interview, July 18, 2017). While scrap metal was found to be a popular source for fabrication in smaller, more rural fabricators, larger manufacturers are likely to use bought raw materials, which places a further bottleneck on large market creation for CA equipment.

3.3.4 Availability

As with service provision, availability of tools is a problem for individual farms (needing more than one tool so more than one laborer may work at a given time), and farmer groups, especially during time-sensitive operations such as planting and harvesting. Ms. Rosemary Wanjiku accesses a shared jab planter through her farmer group, but continues to face issues with accessibility "Everyone wants to use the jab planter at the same time… if we had 2-3 jab-planters, it would be a big help" (Ms. Rosemany Wanjiku 2017, personal interview, June 15 2017).

Chapter 4: Discussion

This section identifies recommendations of interventions to encourage the development of sustainable agricultural mechanization of conservation agriculture per barriers found in the Laikipia case-study. High frequency of issues with lack of finance, inadequate mechanization extension services, and inadequate access to technologies, as well as citation of dis-adoption of CA due to lack of mechanical inputs, indicates potential for improved CA uptake with interventions encouraging SAM mechanization of CA. Case-study findings, as well as larger patterns of sustainable transitions in agri-systems, indicate importance of consideration of each involved sector (market, private industry, technological research and development, consumer behaviour, public policy, international organisations), intersectoral dynamics, and networks which span multiple sectors. Each of these actors have profound consequence on international donor project effectiveness and post-activity outcomes (Sims *et al*., 2015).

Conservation agriculture programs, whether financed by international organisations or national governments, have spearheaded CA's proliferation in multiple countries with high CA uptake- namely Brazil (Junior *et al*., 2012). Accordingly, recommendations are addressed to future CA projects in Kenya; however, due to the multi-sectoral nature of mechanization, roles and duties of other sectors (namely national and regional government, private sector, academic institutions) for enabling SAM of CA at each stage of the project are identified.

4.1 Recommendations

4.1.1 Lack of Finance Available to Farmers:

I. Encouragement of farmer-group formation for improved credit access

For smallholder farmers seeking to purchase CA mechanization inputs for their own use, starting a service-provider side venture, or both, formalised credit access allows for investment in more costly pieces of equipment. Laikipia County is committed to improved credit access for smallholder farmers in its Integrated Development Plan (2013-17), as limited credit access is considered a 'major development challenge' for the poverty reduction goals of the region (Laikipia County Government, 2013). In order to improve credit access, there are multiple issues to consider, the most prominent being limited collateral, high interest rates, and financial institutions' stigmatization against smallholder lending, are marked issues (AGRA, 2014). Drought-prone areas can face added issues in securing credit-lines because of highly variable yields and profits from the rain-fed agricultural sector (Mr. Moses Muchangi 2017, personal interview, June 30, 2017).

While a majority of individual smallholder farmers have limited financial capital with which to pay for the fixed costs of new machines, and limited access to credit-schemes (AGRA, 2014), farmer groups desiring to purchase mechanical inputs typically have higher ability to purchase more expensive machinery through pooled resources, and gain access to credit as a collective at a higher rate than individuals (Eng. Saidi Mkomwa 2017, personal interview, July 24 2017, interview). A commonly utilised course of action is embedding a village savings and loan association (VLSA) microfinance component in a project, in which self-selected group members pool financial resources, and members of the group may take take small loans from the common pool through the purchase of shares (the price of shares is determined by the group from the onset) (Hendricks & Chidiac, 2011). Extra to small-loan access from the scheme, VLSAs have been shown to create a culture of saving and financial management in resource poor areas and improve access to credit and loans, especially from microfinance institutions (Chima J., 2011). In the case of Laikipia, linkage of the VLSA microfinance institutions such as Laikipia's Women's Microfinance Initiative, Juhudi Kilmo (Nairobi), or Care International, can then further expand investment potential of farmer groups' savings.

Per Mr. Moses Muchangi, farmers must be taught relevant financial skills for microfinance to be effective (Mr. Moses Muchangi 2017, personal interview, June 31, 2017). A financial capacity building component for the farmer groups, including education on negotiation and budgeting for purchasing tools and machinery, credit infrastructure, and group-based saving strategies would increase long-term viability of of VSLAs and groups' potential to effectively purchase personal or group mechanical CA inputs.

II. Development of Government Loan Schemes

For improved credit-access nation-wide, Kenya may draw inspiration from Nigeria's Agricultural Credit Guarantee Scheme Fund (ACGSF) as a model for government-supported credit access for smallholders. ACGSF was established by the Nigerian government in 1977 (FAO, 2013), as an initiative designed to provide each category of farmer with access to credit from official sources (*i.e*. banks). As is the case in Kenya, Nigerian banks are not prone to lending to smaller farmers due to 1) inherent unpredictability and risk characteristic of the agricultural sector and, 2) an average necessitated loan size lower than the minimum banks desire to lend (Olaitan, 2006). In response, the Nigerian National Agricultural Cooperative Bank was established within the National Agriculture and Rural Development Bank, and were joined as the Bank of Agriculture. External banks were encouraged by the Bank of Agriculture to open branches in rural regions; a policy mandate was also established requiring a minimum percentage of all loans granted to be towards the agricultural sector (Olaitan, 2006). Continued resistance from banks to offer smallholder credit, largely due to imposed financial risk, gave rise to the ACGSF- a risk sharing formula in which ACGSF undertakes 75 percent of the interest and interest obligation. This scheme has resulted in 647,351 loans having been ensured by ACGSF as of 2009 (FAO, 2013). Agricultural mechanization was boosted as a result; participating farmers reported enablement in purchasing improved agricultural technologies, with post-harvest technologies being cited as the third most important input farmers accessed with the funds (FAO, 2013).

ACGAF has since implemented new models to bolster sustainability; the 'Self- Help Groups Linking Banking Programme was initiated in 1992, and encouraged farmer self-help group formation for the purpose of enabling access to group-savings and loans (FAO, 2013). Prevalence of pre-existing farmer self-help groups in Kenya strengthens the prospect of this model being transferred to Kenya.

The potential success and viability of enabling smallholder credit-access is further evidenced in the FAO sponsored Conservation Agriculture Scaling- Up (CASU) project implemented in Zambia. While machine procurement initially relied entirely on donor supplied machines, private procurement tailored to smallholders later evolved: the AFGIRI and Zambia National

Farmers' Union (ZNFU) methods. AFGIRI is a machinery manufacturer producing CA equipment in Zambia; smallholder farmers may take a loan repayable over three years; other financial institutions responded by creating a comparable loan-agreement, and allow machinery to be collateral in the event of default. This has resulted in expanding the CA service-provision industry in Zambia (Sims, Breen & Luchen, 2015). The ZNFU model tractor mechanization fund of 1.1 million USD was established to gather capital sourced from selling FAO supplied equipment, place those funds into a 'revolving fund' model which pays into either A) tractors and CA attachments or draught animal powered planters or, B) knapsack sprayers for new CA service providers (Sims, Breen & Luchen, 2015).

III. Use of Electronic Vouchers:

Electronic vouchers (e-vouchers) are effectively tickets which can be exchanged for goods or services, and have been promoted as a market-friendly way to stimulate demand for CA services (Nyanga Johenson & Aune, 2011). In Zambia, e-vouchers were distributed by FAO and Mobile Transaction Zambia Limited (MTZL) to lead CA farmers as part of the Conservation Agriculture Scaling Up for Productivity and Production (CASPP) project. The vouchers may be traded for inputs supplied by agro-dealers or approved CA services (Sims, Breen & Luchen., 2015). Permitted CA services are from select providers chosen by the Zambia Ministry of Agriculture and Livestock (MAL) to receive tractors and accompanying CA attachments, as well as technical training and business-skill capacity building. These selected providers participated in the FISRI loan scheme to pay for the tractors, in which the machinery can be repaid over the span of three years within the loan scheme. This e-voucher system effectively stimulates demand for CA inputs and services, as well as guaranteeing clients for new service-providers. It should, however, be noted that a limitation of the the e-voucher system is its restricted capacity to increase input access by farmers not initially targeted by the project.

This system could easily be replicated in Kenya, especially areas in which there is poor service supply network connectivity in communities. Widespread use of mobile-based money transfer application 'M-Pesa' by Vodaphone in Kenya could be an effective platform for e-voucher money transfer between farmers and service providers.

4.2.2 *Inadequate Mechanization Extension Services*

Laikipia County, while committed to CA upscale in its farming sector to improve livelihoods, continues to "face challenges in the delivery of services" (Laikipia County Integrated Development Plan, 2012). The results of the case-study indicated this was due to poor information dissemination of mechanization benefits, lack of introduction to service providers, poorly calibrated machines in mobile CA service providers, and inability of services providers to accommodate demand during peak seasons such as planting time (Moses Muchangi 2017, personal interview, June 30 2016).

I. Implement local vocational training programs for CA service provision

According to Sims and Kienzle (2015) "With smallholder agricultural mechanization and sustainable intensification in rural areas the range or availability of reliable and skilled and appropriately equipped service providers are very limited or non-existent, especially in SSA… Low availability of specialized CA tools and mechanized services in rural areas is common, especially without presence of externally funded aid programs" (Sims & Kienzle, 2015). Increasing the number and skills of CA service providers in Kenya will mean larger range and effectiveness of service provision, provided prospective service providers have feasible options for accessing machines (see 'finance').

Well-tested and affordable training methodologies instructing prospective service-providers in subjects such as market appraisal, equipment selection, calibration, operation and maintenance, and assessment of profitability are aspects in which guidance may be necessary (Sims Sims, Breen & Luchen, 2015). Both components may be included synergistically, as exampled by a CA service provider training program designed by the International Maize and Wheat Improvement Center (CIMMYT) implemented in Bangladesh in 2012. The program collaborated with International Development Enterprises (iDE) and Solar International, a local CA equipment manufacturer, to train and certify CA service providers in land preparation. Solar International imported over 50 seeder/ fertiliser combination attachments for the program. CIMMYT, Solar International and International Development Enterprises conducted a comprehensive training and certification program for the farmers who bought the attachments. To make the program more attractive to farmers, the cost of training was included in the cost of the machinery (CIMMYT, 2016). Additionally, a fifty percent cost-rebate was offered to the farmers who completed the entire course (CIMMYT, 2016). Provision of integrated training programmes such as this one in previous CA project areas (potentially by FAO), as well as universal inclusion in CA future projects, should be strongly considered in Kenya. For added long-term sustainability, service providers should be connected to finance providers and spare-parts dealers/ maintenance services.

II. Targeting local youth for training programs

An issue is the urban- rural migration pattern, especially of young males, which has arisen in Kenya as a consequence of youth seeking less drudgerous, more profitable work in urban centers (Rapsomanikis G., 2015). As a result, the current mean age of the Kenyan farmer is over 60 years old, and a majority are female (Gorman, 2013). As a result, availability of farm labour is decreasing (Mrema, Baker & Kahan, 2008). Mechanization allows for older farmers to avoid overly arduous labor, while simultaneously revitalising agriculture to be a more attractive option for youth.

Opportunity and job creation for youth will therefore serve dual objectives: lessening the youth rural-urban migration trends, and aiding the high youth unemployment rate experienced across Kenya (Rapsomanikis G., 2015). Because youth are typically a less financially empowered group, special financing programs for machinery purchase would encourage involvement. According to Kendat, the lack of vocational training programs is hampering youth from learning the service provision trade and adopting it as a profession. (Kendat, 2016)

III. Establish leading mechanization centers for each region

Regional mechanization centres of excellence can lend long-term viability to mechanization strategies by offering support and services in strategy enhancement, data collection and information, market-linkage services, best practice sharing, standards and certification, and enabling private sector participation. Researchers, contract farmers, agribusiness input providers, financiers, value-adders and market providers (for raw consumers or processing factories) can use the centres to develop the CA machinery/service market and add value to the supply-chain, and as a hub for multi-stakeholder partnerships and business relations to gestate.

These hubs can also serve the important function of hosting farmer field-days for sensitization of CA mechanisation benefits, equipment trails and testing, and service provider training programs. The AMS centres across Kenya may be a good initial facility for accommodating these features.

IV. Facilitated Networking Between CA service providers and CA farmers

In the Laikipia case-study, many interviewees indicated they would utilize CA service providers, but did not know how/ where to access them. Facilitated network creation between certified service providers (trained and certified by CA program frameworks or other appropriate institutions) and new CA adopters, would, therefore, be highly appropriate. This may be done utilizing a formal scheme in which information is relayed through regional extension workers, as all farmers said they personally knew their local extension worker.

4.1.3 Inadequate access to mechanization technologies

I. Consideration of technology access, value-chain approach to continued technology access in project designs

As stated in the 'results' section, previous CA projects in the Laikipia region have neglected to consider sustainable mechanization in their project designs (Eg. Saidi Mkomwa 2017, personal interview, July 24, 2017). Due consideration of the importance of mechanization for CA uptake and upscaling is, therefore, a necessary precursor to addressing mechanization challenges in the local context.

In the past, several international organisations such as the FAO have attempted to bolster mechanisation by donation of machinery and equipment to farmer groups, and government-owned AMSs (FAO, 2013). While these methods were of help to the targeted population, long-term sustainability was not achieved due to lack of inclusion of supply chain in project implementation (AGRA, 2014). Market-based interventions to mobilize the supply-chain of CA tools and equipment can more effectively transform the vicious-cycle of mechanisation occurring in innovation supply and demand into one of sustained growth (Fig. 3.2). This has greater long-term sustainability, and chance of becoming self-sustaining when the intervention is removed.

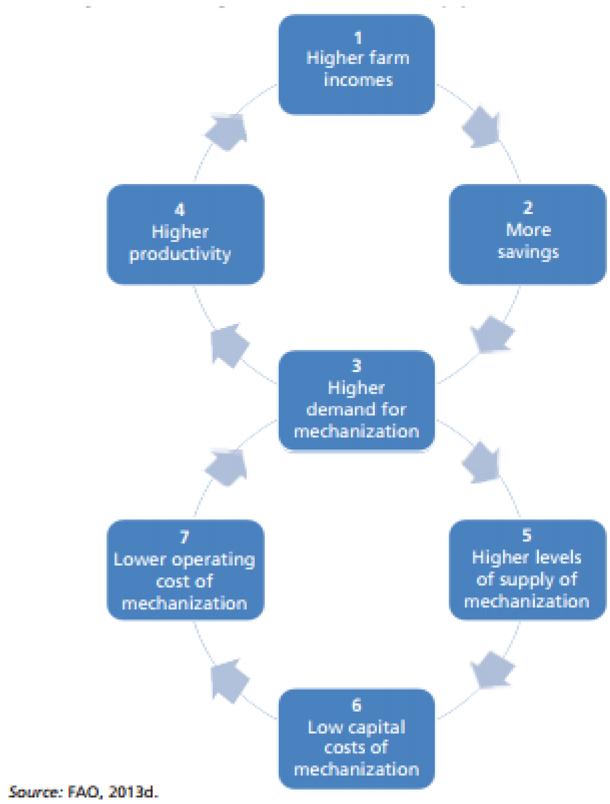


Figure 3.2: Cycle of positive reinforcement occurring from mechanization demand-stimulation (FAO, 2013)

II. Funding for research and development/ improved dissemination of CA mechanization information

Active involvement of research institutions in CA mechanization can investigate viable routes of mechanization, and conduct region-specific studies outlining opportunities, challenges, and trade-offs of mechanizing CA. Data and information are essential for informed policy-making and industry to enable optimal decision-making; however, there is a marked scarcity of current data and information about agricultural mechanization (Kienzle et al., 2013). Per FAO, there is "…need for an intensive and extensive assessment of the current state of agricultural mechanization supply and utilization. This should be followed by projections of the levels of agricultural mechanization which would be required in the future in relation to changing demographics, and demand for agricultural commodities and products" (Kienzle et al., 2013). Kenya's 'Open Data Initiative' is but one online public platform on which key mechanization data and information may be placed.

The potential of this recommendation is revealed in the Bangladesh case-study. The Bangladesh Agricultural Research Institute (BARI) working closely with Bangladeshi CA equipment manufacturers in research and development and promotion (ACT, 2013) has resulted in several Bangladeshi manufacturers lowering embedded costs of production, improving dissemination tactics, and are developing patents for their innovations (ACT, 2013).

III. Improved national and regional policies and initiatives on mechanization

To date, no policy on mechanization in the agricultural sector exists in Kenya (KENDAT, 2016). This is considered the basis for many other challenges faced by the mechanisation sector. Further challenges for mechanisation of CA occur from the simultaneous absence of conservation agriculture in national agricultural policies. As a result, neither CA, nor CA tools/machineries have received any public support to date; support and demand is majorly driven by international donor funded projects, while CA machinery supply is sourced from scattered pockets of private-interest (Kendat, 2016).

Development of a national CA mechanization framework is the foundation upon which wide-scale action must be established. Important aspects of policy development are strategic assessment, and multi-stakeholder inclusion. Strategic assessment must assess the current standing of manufacture, distribution, maintenance, repair, and use of CA tools and machinery. Being that realities surrounding each of these aspects many vary widely between regions and counties, care must be taken to empower of municipal governments to develop appropriate regional strategies which simultaneously support the local community and national strategy. This approach is especially appropriate when considering the devolvement of several functions of the Ministry of Agriculture (MOA). At every scale of the push for mechanisation- from project, to pan-African levels, decision-making should be strongly influenced by study of previous successes and failures of CA mechanization efforts. It is also important to consider that consistency in policy is crucial for market creation and maintenance; frequent loss of consistency in policy creates hesitance, especially by the private sector expressed as lowered participation and investment, as risk-perception is increased.

Although other countries have achieved SAM success without national policy frameworks, having, instead utilized clear law and strategies to address issues of mechanization (National Policy Workshop on Smallholder Mechanization, 2016), developing a policy framework grants facility to align different levels of policy frameworks on CA SAM, from pan-African to local levels, as well as opportunity for collaborative enmeshment with other agricultural development policies and initiatives. Additionally, this would enable future donor projects to work synergistically within the policy structure in order to better achieve mechanization goals.

Even in the absence of a prescriptive mechanization policy, FAO advises making other agricultural development and food-security policies, strategies and programs 'mechanization smart', stating:

> *"Efforts are required to convince public and private sectors of the value proposition of agricultural mechanization so that they can make their current and planned agricultural programmes and business plans 'mechanization smart' – that is to include appropriate mechanization along the value chain the start. The opportunities that mechanization could open for the private sector – including primary producers and their associations, suppliers, financial services providers, and post-harvest handling and marketing agribusinesses – are not currently apparent"* (FAO, 2013).

Whether it is the formulation of policies, strategies or project structure, emphasis should be placed on farmer and other stakeholder input and approval, and incorporating the feedback into their respective structures. For a mechanisation transition to be considered 'sustainable', institutional, economic, social, cultural, and environmental issues, as well as trade-offs, must be considered (Consultative Meeting on a Mechanisation Strategy for Kenya, 2016). Inclusivity of farmers' and other relevant stakeholders' input on individual needs, needs of a community, and identification of local opportunities/ challenges is an opportunity to achieve greater sustainability, community buy-in, and development of realistic/ achievable outcomes. A diversity of farmers, respective of metrics such as age, gender, education, and farm-size will flag areas in which strategies structure many be designed to enhance inclusion of minority or underrepresented groups, thereby increasing rate of uptake, reach, and robustness.

Lastly, learning from past mistakes, such as those in the push for the largely failed African agricultural mechanization of the 1960's, will assist in side-stepping avoidable pit-falls and oversights in policy development and approach.

IV. Further exploration of increased two-wheel tractor powered CA operations

In the case of Kenyan smallholders, there is much evidence that two-wheel tractors (2WT) should be a promoted machinery for smallholder farmers because of decease in the presence of draft animals due to drought, ability to accommodate CA attachments, simpler maintenance and repair services of 2WT, greater cost-effectiveness, appropriateness for small, fragmented farm configurations, and versatility (Baudron *et al*., 2015). In addition to land preparation, weed management and harvest activities, 2WT can be used for farm-market transport and small-scale irrigation pumps, creating synergistic opportunity (Baudron *et al*., 2015). Bangladesh experienced marked success of CA mechanization via the 2WT under similar agronomic and socioeconomic conditions (Hossain *et al.*, 2015). Even though only one in thirty Bangladeshi farmers own a 2WT, nearly all farmers, even the poorest, have access to 2WT's because of commonality of service provision by farmers who own the tractors (Baudron *et al*., 2015). Moreover, as compared to four-wheel tractors (4WT) 2WT provide high rate of return for service providers (Paman *et al*., 2010). The virtually universal accessibility in Bangladesh can be attributed to this high return rate, and the resultantly lowered prices of service provision as compared to 4WT or draught-animal powered services (Baudron *et al*., 2015). Currently, number of 2WT imported in Kenya is low relative to 4WT (Fig. 3.3, 3.4), there is potential for 2WT importation to further proliferate in the tractor and service provision markets to lower the cost of mechanized CA operations. However, it should be noted that the success of the private-sector driven mechanisation model in Bangladesh was made possible by initially supportive government policies to lower barrier to entry for 2WTs (1988 abolishment of standardization restrictions and levy taxes on 2WTs), (Diao *et al*., 2012, Baudron *et al*., 2015). The policy environment in Kenya is distinctly less enabling.

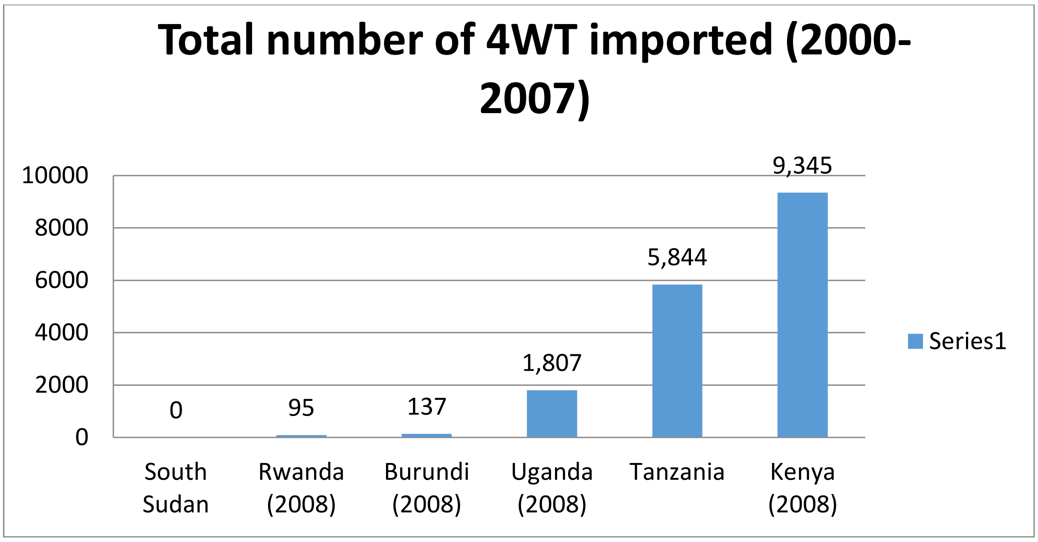


Figure 3.3: Total Number of 4WT imported in Kenya: 2000-2007 (Kaumbutho, 2016)

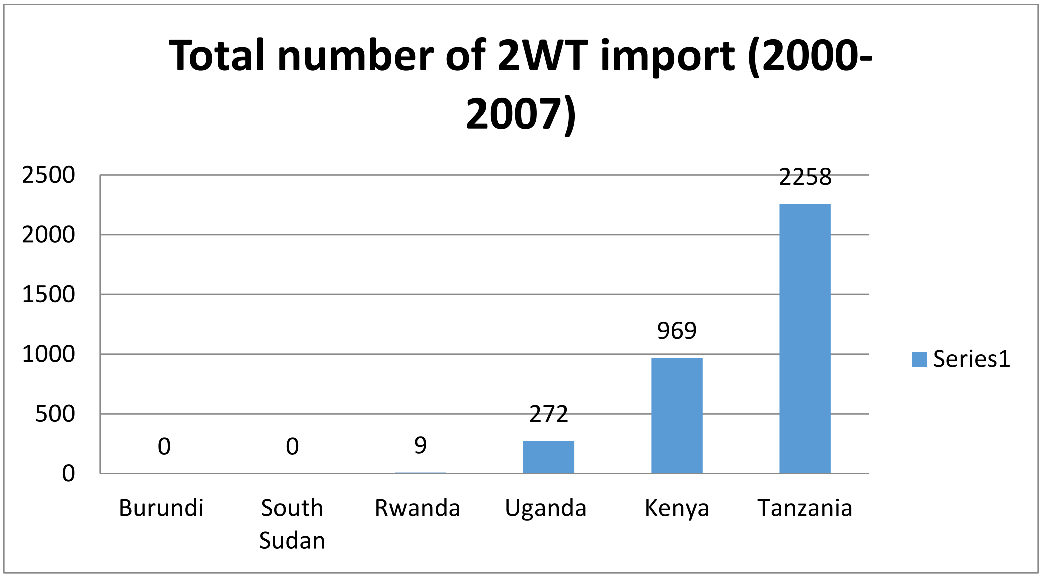


Figure 3.4: Total number of 2WT imported in Kenya: 2000-2007(Kaumbutho, 2016)

V. Identification of suitable business-models for smallholder CA mechanization within regional contexts

Capacity for long-term independence and effectiveness should be the key driver behind choosing a mechanisation approach/business model; capacity to bring about social benefits should also weigh-in heavily, as this will enhance the sustainability of the model. Previous studies on financial sustainability of public-sector operated mechanization services have uncovered generalized patterns of ineffectiveness (Habitu *et al*., 2013). The 1960s push to mechanize Africa failed, in part, due to the approach of government interventions and their outcomes; that is, low-efficiency, high-cost mechanisation (Diao *et al*., 2012). Consistent with these findings, Kenya's public-run Agricultural Mechanization Stations (AMS) have not been shown to be an appropriate or sustainable mechanization model in SSA (Diao *et al.*, 2012). Private-sector leadership in mechanization has experienced unique challenges, namely with adequate demand, but has resulted in better efficiency and affordability, especially with imported machines (Diao *et al*., 2012).

Public-private partnership (PPP) models combine public support with private-sector expertise, and have potential to rapidly expand institutional capacity (FAO, 2013). Considering the centrality of a well-functioning supply-chain in successful sustainable mechanization, and PPP's have been considered to be a 'best-bet' route for making value chains function in all stakeholders' interests (Sims *et al.*, 2017), PPPs have the potential to be a long-term sustainable solution for SAM of CA.

The private sectors' connection with profitability ensures cost-effective solutions, especially if the private-sector is well informed by market studies and research networks and is supported by public funds. Utilizing the PPP model in the Zambian CASU project allowed for the inclusion of inbuilt finance schemes, as well as bundling of CA services, resulting in greater access to the service-provision profession and multiple mechanization options for smallholders practicing CA (Sims, Breen & Luchen, 2015).

As found in the case-study (see 'results'), while the case-study found well-maintained machines and trained service providers at the Agrimench Hub (privately-run), there were problems with large distances between farms, and accommodating demand surges due to limited number of machines. This model has formed a common front with AGRA, ACT and FAO, but has not partnered with the MOA or other relevant government branch; such a partnership has great potential to increase the operational capacity of the hub (Dr. Pascal Kaumbutho 2017, personal interview, July 18, 2017). Aforementioned inadequacies could be alleviated by establishing more Agrimech Hubs around the country, improving interconnectivity of hub to other PPP centres to accommodate regional demand fluctuation, supported acquisition of the most appropriate machines (in terms of investment payback and local conditions), and possibility for subsidy-supported demand-creation and training programs.

An important caveat to consider is that specialized mechanization services only become profitable/ attractive to the private sector with achievement of a certain density of demand (Diao *et al*., 2012). Factors such as farmer demand and investment capacity can be investigated by research institutions, and used to support informed decision in the private sector of appropriate markets. Where establishment of a mechanization hub would be financially insensible, training farmers who own 2WT or other purchased machinery may be the most feasible to service provision formation, as is exampled in the Bangladesh case-study. Farmer-farmer service provision already exists to some extent in Kenya and Laikipia, but could be further strengthened on the project, regional, and national levels.

VI. Encourage local manufacture

A critical element of Brazil's success in mechanizing CA was utilizing indigenous knowledge of agronomic conditions to formulate correspondingly appropriate tools (Junior et al., 2012). As mentioned, local manufacture ensures tools and machineries are designed in adherence to local conditions- an aspect in which imported tools are often ill-suited (FAO, 2013). Additional benefits are job creation and rural economic development. In Bangladesh, for example, the 2WT and small diesel engines industry is valued at over 200 million USD (ACT, 2013).

The barriers to a CA supply-chain with local inputs are numerous, including lack of capacity of local artisans to produce quality tools, especially in initial stages, and machine/ steel manufacturing taxation policies giving favour to imported machines. The absence of import tax for imported agricultural machinery, contrasted with presence of import tax for crucial machinery fabrication inputs such as steel disincentivises local manufacture via reduction of profit and market space for locally produced mechanical inputs (Sims *et al*., 2012). Larger manufacturers are disproportionately affected by this effect, as smaller artisans may use scrap metal for fabrication. Development of supportive tax policies, such as was done in Bangladesh (ACT, 2013), is a necessary precursor for development in this area. Whether local manufacturers sell products to agro-dealers or directly to farmers, network creation, and seller-buyer interactions may require facilitation. Assistance for rural-urban linkages may be especially apt for regions with a weak or unreliable local fabrication sector, as Nairobi, Kenya has various private agro-manufacturers.

If local manufacturing industry is deemed unsuitable or is slow to stabilize, institutional support for enterprises such as Brazafric- an importer and distributor of high-quality conservation agriculture equipment from Brazil for Kenya, Tanzania, Uganda, Rwanda, Ethiopia and Mozambique- is an alternative pathway to securing supply.

VII. Training packages for local fabricators/ lead-farmers

Though it has received increased attention in recent years, the inclusion of training packages for fabricators has not traditionally been featured in past CA projects in Kenya (Eg. Saidi Mkomwa 2017, personal interview, July 24 2017). Capacity-building and development of local fabricators abilities will boost job-creation and livelihoods and increase the competitiveness of local technologies. Research and development of optimal tools and machineries, also considering socio-economic realities and capacities of the end user (smallholder CA farmers) is an invaluable aspect which will support the training packages for fabricators. Inclusion of a platform for input sharing of local fabricator and farmers on equipment development is an addition which could greatly expedite suitable tool development. As in the case of Brazil, training on adapting conventional planting machineries to support CA functions is also essential for a cost-effective SAM transition, specifically in initial CA demand creation stages (Junior *et al*., 2012).

Other considerations for developing this recommendation include:

- Formalized collaborations and network-creation between established conservation agriculture fabricators and apprentices. This was shown in FAOs Conservation Agriculture for Sustainable Agriculture and Rural Development (CA-SARD) project, in which private sector interaction between Brazilian and East African fabricators and manufacturers, was facilitated by the project (ACT, 2017). The FACASI project organized a two-week study tour to Bangladesh for African mechanization stakeholders
- FAO sponsored conservation agriculture mechanization projects in Zambia placed specific focus on sustainable training methods. In addition to training participants, 'lead-

farmers' were also trained to train others in order to ensure post-project upscaling. They were provided with machinery through subsidies and e-vouchers (FAO, 2016).

VIII. Bolster private-sector involvement

Less obvious potential benefits of mechanization to the private sector is problematic in Kenya, and wider SSA (Kienzle et al., 2013). As mentioned, stimulation of private sector interest is of paramount importance to break the vicious cycle of mechanization, especially during the initial demand-creation stage.

Government expenditure and subsidies for agriculture is notably low in Kenya (Benin, McBride & Mouges, 2016). Government subsidy has been shown to be an effective method of stimulating private sector interest and investment in mechanisation during the initial transitional period from manual to mechanized farming (Daio *et al*., 2012), notably in CA's transitional pathway in India and China. Importantly, the subsidies' removal after critical mass and economy of scale were achieved did not result in the weakening or dissolution of the private supply-chain. Subsidies generally take two forms when addressing mechanisation, either targeting a wide breadth of hand-tools, draught animal equipment, or diesel-powered machines, or focusing the subsidy on new-development of select mechanical implements which are suitable for regional conditions (Diao *et al.,* 2012). Either subsidy route can have the effect of establishing connection between end-users and suppliers; it should, however, be noted that subsidy design should be such that market distortion is minimized; subsidies targeted at private sector development and participation contribute to long-term sustainability and efficiency. More specific subsidy recommendations based on successful mechanization subsidy structure in Bangladesh, are explicated below:

1. Provision of subsidies encouraging importation of CA machinery and spare parts by private companies
2. Subsidizing CA extension-services, especially training sessions
3. Government promotion of sale of CA machinery, targeting private sector agro-dealer buyers

Other methods of stimulating private sector interest include:

1. Facilitated involvement of the financial sector may also have a staunch influence on private sector interest and participation
2. Organizing regular CA mechanization exhibitions and trade-fairs
3. Public research and business development services (Kienzle *et al.*, 2013)

4.2 Study limitations

Several limitations were encountered over the course of the study.

4.2.1 Data gaps

There were multiple instances of non-existent or outdated data sources for topics such as, but not limited to, current data on CA uptake in Kenya and Laikipia, quantified benefits of CA4FS, CA4FS baby-demo farmer data, numbers of each type of machinery in Laikipia county, etc.

4.2.2 Lack of representative sample

Due to time and resource constraints, a very limited number of farmers and members of other stakeholder groups were reached. A larger sample size would have given a better representation of the diverse perceptions and realities of mechanisation. Ability and time to survey CA4FS farmers in Machakos county would have been ideal; that way, contextual factors and their effects on SAM of CA would have been more apparent from the research, rather than attempting to compare results of case-studies of very different scope, timelines, and designs.

The same concept applies to the other stakeholder groups, especially to the private service provider stakeholder group. The two service providers regularly serving Laikipia through Agrimech were away for each of my field trips to Laikipia.

4.2.3 Communication barriers

As is the nature of any cross-cultural communication, potential miscommunication and/or misinterpretation is an unavoidable risk. Though there was a translator present, important nuances may have been missed, and the interviewees may have felt less comfortable speaking through a translator, potentially altering their responses or limiting the conversation from the 'flow' which is typical of semi-structured interviews.

4.2.4 Questionnaires

Although questionnaires were developed with the literature review, as more interviews were conducted, more topics and areas of interest emerged that deserved further investigation. The semi-structured interview setup allowed for such deviations, but overall trends of the question responses could not be garnered if only discussed with select participants.

4.3 Areas of future study

Two main areas of future research were identified by the study:

1. How will mechanization of smallholder farms in Kenya will affect its agricultural sectors' carbon footprint? The carbon-footprint of farms?

Advocating for SAM of CA as a sustainable, climate smart solution comes with a dose of irony when referring to diesel powered tractors, given that a majority of anthropogenic greenhouse gas emissions are sourced from burning of fossil-fuels. Trade-offs between greater adaptive capacity in smallholders, but increased emissions from AM, should be assessed.

2. What will the knock-on effects of smallholder mechanisation be for rural employment?

While mechanization is considered a vital component of sustainable intensification, advocacy must be met with consideration of wider impacts. How mechanization will impact local labour markets, and its potential for diversifying income streams, is an ongoing debate, as many people, especially women, derive their livelihoods from these manual jobs, so mechanization may have kick-back effects of increased poverty or unemployment of already vulnerable demographics. However, other bodies of research indicate mechanisation has a positive effect on local employment through development of new opportunities. Analysis of specific impacts in Laikipia would be beneficial in further assessing the suitability of SAM for Laikipia and informing project design considerations to eliminate or lessen negative effects on employment and income-security.

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Appendix I: Smallholder Farmer Questionnaire

Pt. I:

1. What products does your farm produce?
2. Since the project's closure last year, are you practicing CA? what CA options have you adopted?
3. Why did you choose this method over the others?
4. Have you consistently applied this method to all of your plots?
5. Over the last year, under your chosen system, have you perceived any changes in terms of

a. yield,
b. labor,
c. profits,
d. inputs (such as fertilizer)
e. weeds/pasts
f. water-use

6. In recent years, have you experienced changes in climate, growing times or rainfall patterns which have affected the farm?

Pt. II:

7. What are the main challenges that you have experienced with your chosen farming method in the past year?
8. What, if anything, would help you address the challenges experienced?
9. What new tools were needed for your chosen farming system?
10. Have you been able to access all of the appropriate technology for your chosen farming method in local markets?
11. Has the technology been affordable?
12. Have you or a farmer group you are involved in received equipment, or had access to subsidized equipment?
13. Do you use service providers? If so, which (and why)? (AgriMech hub, nomadic, another farmer?)
14. How were you connected to these CA service providers?
15. Have you faced any issue with needing to buy more livestock fodder/building materials (or other inputs) as a result of using crop residue for CA purposes?
16. Are you currently part of any coalitions, field schools, or groups of other farmers also practicing CA? If so, how often do you meet?
17. If you needed more information, or advice about CA practices or challenges, who would you contact?

Pt. III:

18. Will you continue the same options for future growing seasons?
19. Would you recommend the practices to other farmers in your area?