The social-ecological sustainability of the Tiyeni deep-bed conservation agriculture system in Malawi

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Abstract

Food insecurity and rising poverty levels remain Malawi's major development challenges given the country's reliance on rainfed agriculture, leaving millions of families vulnerable to pangs of the ever-present social and ecological perturbations. Coupled with extreme poverty levels, unsustainable agricultural practices and high population growth, climate change projections point to a bleak agricultural future that threatens the already struggling food production systems among resource-poor smallholder farmers. The past two decades have seen rising advocacy for Conservation Agriculture (CA) practices as pathways to attaining food security, poverty amelioration, and environmental sustainability. Evidence of poor CA adoption across Sub-Saharan Africa (SSA) points to the technology's ineffectiveness and unsuitability among smallholder farmers of varying socio-economic statuses and environmental conditions in the region.

Encapsulating the complexities of CA in SSA is the novel Deep-Bed Farming system (DBF) as championed by Tiyeni Malawi Ltd in northern Malawi. While anecdotal evidence suggests that the DBF significantly contributes to soil and water conservation and increases crop productivity, there remained significant knowledge gaps to understand what works, where, why and how. Paramount to these questions are the different scenarios that explain how site-specific environmental and social factors influence which DBF components, key interactions and feedback mechanisms among these and outcomes of such interactions. The study aimed to analyse impacts of the DBF on soil physical and chemical characteristics and how these influence maize productivity; examine the farming system's contributions to farmers' livelihoods; examine DBF's contributions to farmers' social capital, institutional sustainability; and explore on-farm DBF adaptations as strategies for site-specific adaption and learning for building resilient smallholder farmers' agricultural systems.

Achieving this complex task required holistic and interdisciplinary research approaches that would help bridge the long-term disciplinary divides in agricultural and rural development research. One essential approach is the Social-Ecological Systems Framework (SESs). Applying SESs thinking, the study was divided into two main categories: on-farm soil and water participatory monitoring and assessment of DBF's livelihoods and institutional sustainability. In both cases, holistic and interdisciplinary Participatory Learning and Action (PLA) methods were used for data collection and analysis. The study was conducted in six communities of farmers within 45km radius of Mzuzu city where the DBF was first developed and promoted since 2005.

Results showed that the DBF resulted in immediate improvements in soil's physical parameters like de-compaction, rainwater infiltration and significant reduction in soil erosion. Conversely, marginal increases in nitrogen, organic matter and organic carbon levels were recorded. Consistently high maize yields in all DBF plots were recorded with further analysis showing strong correlation to changes in soil' physical conditions.

The extent to which improved maize productivity translates to improved livelihoods is limited by small plot sizes under the DBF and a farmer's assets endowments. The former is embedded in complex social-ecological situations of labour dynamics, handouts, and imperfect extension system. Regardless of plot sizes, the poorest of society, widows, and the elderly under acute food shortages benefit the most from high maize yields and income savings than wealthier farmers. Conversely, wealthier farmers stand to benefit the most should they be willing to independently invest in the DBF.

Whereas farmers' connections and interactions among themselves increases as they engage in group DBF activities, connections to influential sources of information and resources remain insignificant. Due to lack of emphasis on knowledge exchange and diversification in Tiyeni's extension system, social capital declines as farmers' groups become inactive and Tiyeni reduces its contact frequency with farmers. Sharing of information is gradually limited and farmers adaptive capacity weakened. Similarly, farmers actively experiment with components of the DBF besides the farming system being an experiment in its own right. Because of top-down extension approaches, adaptive learning, and generation of site-specific DBF knowledge and experiences remains limited. Overall, adaptive capacity as a critical aspect of resilient and sustainable social-ecological systems is limited.

The study makes original contributions to knowledge by (1) applying the SESs thinking and associated theories and concepts to studying DBF, and by being the first study to apply SES thinking in CA it provides important lessons for future CA studies seeking to better understand such complex issues. Second (2), it provides a synthesis of the results to model social-ecological scenarios and outcomes that explain environmental and social dynamics of the DBF among smallholder farmers in Malawi. By doing this, the study illustrates what social-ecological conditions support the DBF, what components of the package are suitable, where and for who. Finally (3), the study also provides rationale for considering site-specific uniqueness in delivering CA sustainability across SSA. In particular, it makes significant contributions to CA debates and literature surrounding its appropriateness and suitability in SSA, top-down CA technology transfer, dis-adoption and its sustainability. More generally, lessons learnt through this study will reshape future DBF and other CA practices, helping various agricultural stakeholders to significantly contribute to the improvement and sustainability of millions of resource poor farmers' social-ecological systems beyond Malawi.

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Abbreviations

AEDC	Agricultural Extension Development Coordinator
AEDO	Agricultural Extension Development Officer
BD	Bulk density
CA	Conservation agriculture
CFU	Conservation Farming Unit (in Zambia)
CR	Conventional Ridge-based farming
DAES	Department of Agricultural Extension Services
DBF	Deep-bed farming system
DFID	Department for International Development
EC	Electrical conductivity
F2FE	Farmer-To-Farmer Extension
FFSs	Farmer Field Schools
FAO	Food and Agriculture Organisation of the United Nations
GHGs	Greenhouse Gases
GR	Green Revolution
INGO	International Non-Governmental Organization
LRCD	Land Resources Conservation Department
MK	Malawi Kwacha
MoA	Ministry of Agriculture
NCATF	National Conservation Agriculture Task Force
NGO	Non-Governmental Organisation
OC	Organic carbon
OM	Organic matter
PCA	Principal Component Analysis
PLA	Participatory Learning and Action
PRA	Participatory Rural Appraisal
SESF	Social-Ecological Systems Framework
SESs	Social-ecological systems
SFT	Space-For-Time substitution
SLF	Sustainable Livelihoods Framework
T/A	Traditional Authority
ST/A	Sub-Traditional Authority
USAID	United States Agency for International Development
ZNFU	Zambian National Farmers Union

Chapter 1

Introduction

1.1 Research Context

FAO (2020) recently reported that the SDG of ‘achieving zero hunger and eradicating poverty in all its forms around the world’ (UN, 2015) remains one of the most significant and complex interlinked challenges of the century. The 2020 FAO Report also shows that 2020 was particularly challenging year due to the outbreak of Desert Locusts in East Africa as well as loss of livelihoods due to the impacts of COVID-19. Latest global projections show that COVID-19 alone may add between 83 to 132 million people to increase the number of undernourished people from 690 million as of 2019 to over 750 million by the end of 2020 (FAO, 2020; WFP, 2021). Amid growing population and shocks and pressures because of climate variability and change that threaten the very existence of food production systems (World Bank, 2010; Chinsinga, 2012; IPCC, 2014; Asfaw et al., 2017), these challenges are more pronounced in the Sub-Saharan African countries (SSA) with agrarian economies, little livelihood diversification and overreliance on rainfed agriculture (Godfrey et al., 2010; Charles et al., 2010; FAO, 2015). According to Porter et al. (2014), subsistence smallholder farmers will increasingly become vulnerable to increased climate-related stresses like droughts, heavy storms and pests and diseases given their dependence on maize-based rainfed cropping systems.

While the Green Revolution (GR) significantly intensified and improved food production through the introduction of agricultural mechanisation, improved seed varieties, inorganic fertilizer, and herbicides application in the mid-20th century elsewhere (Hazell, 2009; FAO, 2011), these success stories were uncommon in SSA (Frison, 2008). Due to its focus on increasing food production levels by increasing inputs and other intensification mechanisms, the GR led to the realisation that food production without consideration of the environment on which food systems are built was increasingly leading to irreversible damage and degradation to important land and water-based resources (Wezel & Soldat, 2009; Wibbelmann et al., 2013). According to Evenson and Gollin (2003), Reynolds et al. (2015) and Dawson et al. (2016), challenges of the Green Revolution included:

a) The degradation of the environment, loss of biological diversity (biodiversity), and water pollution through eutrophication.
b) Emission of greenhouse gases and hence climate change with unprecedented impacts on the hydrological cycle and human systems with the poor suffering the most.
c) Over-reliance on non-renewable resources such as machinery and fossil fuels.
d) Soil degradation characterised by compaction, wind, and water erosion.
e) Increased cases of cancer due to consumption of agricultural chemicals through water and food and
f) A prescriptive top-down technology transfer extension approach that regards farmers as mere end users with primitive knowledge that needs to be modernised.

Consequently, the need for sustainable means of food production that reduce negative environmental and societal impacts while meeting current and future production and consumption needs became more urgent (Pretty et al., 2005; Hazel, 2009; Godfrey et al., 2010; Pretty et al., 2011). The 1930s saw increasing realisation that agricultural systems are integral parts of the human systems such that the former cannot be fully understood and improved without the latter, forming the basis for contemporary agroecology (Dalgaard et al., 2003; Wibbelmann et al., 2013). More so, agroecology, which Dalgaard et al. (2003: p. 39) defines as "*the study of the interactions between plants, animals, humans and the environment within agricultural systems*" was an attempt to move away from positivistic, reductionistic, and disciplinary approaches to holistic systems approach to knowledge (Wibbelmann et al., 2013). With emphasis on diversification, food sovereignty, energy efficiency, principles of agricultural sustainability and application of long-term traditional agricultural knowledge systems (Scoones, 2009), agroecology is meant to lead to farmers' self-sufficiency, resilient and adaptive farm systems while countering challenges of GR.

The Millennium Ecosystem Assessment Report (MEA, 2005) among other preceding works further highlighted the inextricable relationships between the environment and human systems and the nested relationships among them. Thus, instead of a singular focus on food production maximisation, there existed a paradigm shift towards the concept of agricultural sustainability that stressed the need for novel agricultural technologies that provide win-win situations (Godfrey et al., 2009; Pretty et al., 2011). Pretty et al. (2011: p. 7) defines the concept of sustainable agricultural intensification as:

> "*…producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services*".

1.2 Social-ecological Systems: A holistic framework

While previous views on agricultural sustainability provided better understanding of the cause and effect between the environment and agriculture, they effectively excluded unique farmer conditions that determine suitability, extent of contributions of a particular agricultural technology and long-term adaptation and sustainability (Pretty et al., 2011; Nkala et al., 2012; Andersson & D'Souza, 2014). Recent studies have pointed to a need for more holistic approaches to agricultural intensification and research that recognise the interactions and feedback loops among human and ecological systems and a push away from top-down technology transfer to farmer centred extension systems (Nkala, 2012; Giller and Andersson, 2014; Giller et al., 2015).

As opposed to conceptualising sustainability as an end result in itself, Gunderson and Holling (2001) and Agrawal et al. (2006) considered this as a continuous process of learning, adaptation, and re-innovation through their adaptive cycle and panarchy theories. One example of holistic approaches is the Social-ecological Systems (SESs) (Ostrom, 2009; McGinnis & Ostrom, 2014). The SESs approach evolved from the complex systems thinking which recognise and embrace complex relationships and feedback loops that exist in human and environmental systems (Ostrom 2005; Agrawal et al., 2006; McGinnis & Ostrom, 2014). The central argument being that a better and integrated understanding of existing farming systems requires a more holistic and nuanced approach that goes beyond disciplinary research approaches.

1.3 Conservation Agriculture: A new panacea for SSA?

Conservation agriculture (CA) evolved in the Americas from the need for more sustainable soil and water conservation techniques meant to reduce soil and water degradation, reduce fuel costs while improving crop productivity by maintaining hybrid varieties and use of herbicides to control weeds (Thierfelder et al., 2005; Baudron et al., 2007; Hobbs, 2007; Andersson and D'souza, 2014). The FAO (2008, p. 1) defines CA as:

> "A*n approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment.*"

CA practices are characterised by three main principles of zero/minimum tillage, permanent organic soil cover and crop diversification and rotation. The first principle entails an emphasis on the need to reduce tillage activities and maintain a healthy soil ecosystem (Shaxson et al., 2014; Kassam et al., 2015) which is intricately linked to the principle of permanent organic soil cover through crop residue retention and use of cover crops (Theirfelder and Wall, 2010; Erenstein et al., 2012). Correspondingly, the third principle advocates for the diversification of crop production systems to reduce the impact of crop failure and crop rotation across both space and time, a proven approach to reduce crop diseases and pests and improve nutrient utilisation in the soil profile (Kassam et al., 2009; Sosola et al., 2012; Thierfelder et al., 2012). Based on its success in South American, CA has been promoted as an example of appropriate technologies that can be adapted to specific agroecological requirements, improve on GR technologies and as a form of climate-smart agriculture (FAO, 2010; Concern Universal, 2011; Kassam et al., 2014; Theirfelder et al., 2016).

Conversely, evidence from its application across SSA countries points to a 'one-size-fits-all' approach that has disregarded the site-specific differences at different hierarchical levels (Halbrendt et al., 2014; Baudron et al., 2014; Giller et al., 2015). Until Giller et al (2015) questioned the suitability, impacts and adoption figures among smallholder farmers in SSA region, CA had received overwhelming backing from research and development communities, government departments, the faith community and private companies as a panacea for solving hunger and poverty problems in Africa.

In SSA, CA has been characterised by poor adoption with apparent dis-adoption among smallholder farmers in the last two decades (Ngwira et al., 2014; Mloza-Banda et al., 2016; Brown et al., 2017), indicative of mismatches between claims and expectations of CA advocates and farmers' own experiences. Much as improved soil and water parameters and crop productivity levels in semi-arid environments have been reported elsewhere, normally after a long and consistent crop residue retention (Thierfelder et al., 2016; Steward et al., 2018), evidence of worsening soil degradation and reduced crop yields have also been established (Andersson & D'Souza, 2014; Giller et al., 2015). While other authors have raised concerns over the lack of CA tailoring to smallholder farmers' context in SSA (Giller et al., 2009; Andersson & D'Souza, 2014; Kassam et al., 2014), it is yet to be known how the technologies contribute to win-win situations under specific social-ecological conditions.

Most notable benefits of long-term consistent CA practise are the increased yields where moisture is the only limiting factor, improved soil quality and reduced soil erosion with long term consistent crop residue retention, and reduced labour demand with the use of herbicides (Nkala, 2012; Ngwira et al., 2014; Theirfelder et al., 2016; Steward et al., 2018). While these carefully designed and controlled studies provide evidence for the effectiveness of CA, evidence from on-farm studies show that resource poor smallholder farmers have to endure crop yield penalties in the first five years of practice, increased soil erosion where residue retention is absent or materials are insufficient, outbreaks of seedling-eating pests, increased labour demand, dessication of top soils and further compaction of untilled soil layers among others (Giller et al., 2009, Corbeels et al., 2014, Halbrendt et al., 2014; Anderson & D'Souza, 2014). A case in point is the new set of practices collectively called deep-bed farming system (DBF) that demonstrates current CA knowledge gaps, controversies, and debates (see Section 1.5 and Mvula & Dixon, 2020).

1.4 Food security, agriculture, and CA in Malawi

Despite various efforts to reduce poverty and eradicate hunger, Malawi remains one of the poorest countries in the world, ranking 174th on UNDP's Human Development Index (0.483 in 2019) (UNDP, 2020). A significant percentage of the population remains below the poverty line, with as many as 52% surviving on less than US$1 per day and 22% barely making ends meet (NSO, 2019; World Bank, 2019; UNDP, 2020). The country's economy remains undiversified. Agriculture contributes about 26% and over 40% of the Gross Domestic Product (GDP) and Gross National Income (GNI) respectively (World Bank, 2019). The ailing sector employs over 86% of the population, especially the rural population that makes up 84% of the country's population (NSO, 2019; Asfaw et al., 2018). The sector itself is undifferentiated; maize (*Zea mays*) remains a dominant crop being cultivated on over 70% of the arable land as a food crop followed by tobacco (*Nicotiana tabacum*), tea (*Camellia sinensis*), sugarcane (*Saccharum officinarum*), and macadamia (*Macadamia integrifolia*) as main export crops (FEWS NET, 2016). As the agricultural productivity deteriorates due to land fragmentation and soil fertility degradation, increasing poverty levels and recurring climate related stressors, the country's socio-economic development remains ominous.

As food insecurity among resource poor smallholder households continued to resist past efforts, the Malawi government introduced the input subsidy programmes to enable poor families to access improved seed and fertilizers (Chibwana & Fisher, 2011). Inadvertently, government subsidies have also increased maize monocropping among smallholder farmers, increasing their vulnerability given the crop's high sensitivity to climate-related stressors and soil degradation (Chibwana & Fisher, 2011; Thierfelder et al., 2013b). Along with relief packages embedded in agricultural promotion projects commonly by Non-Governmental Organisations (NGOs), input subsidies have normalised the provision of handouts, casting doubt on the sustainability of agricultural development. This raises questions regarding the impacts of these projects on farmers' livelihoods and their environment amid concerns of their long-term sustainability beyond funded promotion programmes (Andersson & D'Souza, 2014).

Malawi's agricultural system is dominated by smallholder susbsistence farmers who cultivate about 96% of the arable land. The major practice is the annual remaking of raised seed beds popularly known as conventional ridges (CR) to a height of about 15-20cm where farmers make these ridges on previous furrows normally associated with burning of crop residues for easy land clearing, a practice adopted in 1930s during colonial times until the Sasakawa Global 2000 (Kumwenda, 1990; Chibwana et al., 2012). Similar to planting stations (crop spacing), these ridges do not follow specific measurements; they could be between 75cm to 100cm apart and between 10-20cm in depth. According to Douglas et al. (1999), Shaxson and Barber (2003) and Shaxson et al. (2014), the annual remaking of these ridges to the same depth creates hardpans, a compacted layer of soil just below the annualy cultivated depth.

These hardpans impede crop root development, reduce rainwater infiltration rates, encourage accumulation of surface water, surface sealing, poor soil aeration and consequently leading to soil erosion and reduced soil fertility among others (Snapp, 1998; Shaxson et al., 2014). According to the Shaxson et al. (2014) and FAO (2018), the country loses 29t/ha/annum of top-soil per year with significant drop in maize productivity without the use of inorganic fertilizers to correct for the lost soil fertility. As this trend continues, Malawian soils are becoming less productive, requiring more investment in inorganic fertilizers to replenish lost soil fertility for optimum maize production. Coupled with high poverty levels, reccuring climate related shocks and pressures and market failures, the majority of Malawians remain trapped in food insecurity and worsening living standards.

Agricultural development in Malawi remains stagnant owing to inefficient extension system that limits exchange and spread of new agricultural information. In a drive to improve provision of extension services, the Department of Agriculture Extension Services (DAES) under the Minstry of Agriculture adopted a pluralistic extension approach (Masangano & Mthinda, 2012; Kundhlande et al., 2014; Khaila et al., 2015). While this has been an important step toward development of a bottom-up extension system, Ragasa and Niu (2017) found that agricultural extension service provision in Malawi remains poor. Save for NGO-based agricultural promotion projects participants, few farmers are able to demand such services from DAES staff (Ragasa et al., 2016;

Ragasa & Niu, 2017). Moreover, the few DAES field officers, especially the Agricultural Extension Development Cordinators (AEDC) and Agricultural Extension Development Officers (AEDO) lack the motivation and means to deliver their services to farmers owing to mobility challenges and poor pay (Khaila et al., 2015; Ragasa & Niu, 2017). Despite decades of efforts in promoting sustainable farming methods, crop productivity remains poor; between 1.5 and 2.5 t/h compared to 5-8 t/h global potential (Sosola et al., 2012; Brown et al., 2017). Combined, all these challenges coupled with climate variability and change exacerbate food insecurity and poverty levels among the Malawian populace (Pretty et al., 2011).

Fundamentally, these inextricably linked challenges exemplify the very nature of complex social-ecological challenges at different levels; from individual farmers, households, communities and the country at large. To better understand these challenges and to offer improved solutions, a more holistic Social-Ecological Systems Framework is required. There exist an urgent need for novel farming systems in Malawi that can increase agricultural productivity while sustaining the environment on which farming relies. It is within these spaces that the deep bed farming system (DBF), which encapsulates these social-ecological challenges, finds its niche.

1.5 The deep-bed farming system (DBF)

Since 2005, Tiyeni Malawi, a small charity organisation in northern Malawi, had been championing the DBF which was formed by a small team of soil and development practitioners due to widespread soil compaction in smallholder farmers' fields (Shaxson et al., 1997; Snapp et al., 1999). The DBF is a modified form of CA which integrates 30cm deep tillage in the first year of implementation and organic manure application with CA's principles of reduced tillage in subsequent years, permanent organic soil cover and crop diversification and rotation. The initial deep tillage is designed to break hardpans below the annually cultivated zone in CR (15-20cm) that aims to achieve a de-compacted and improved soil profile that allows rainwater infiltration, reduces surface runoff and soil erosion, crop root development and improved microbial activities in the subsequent years.

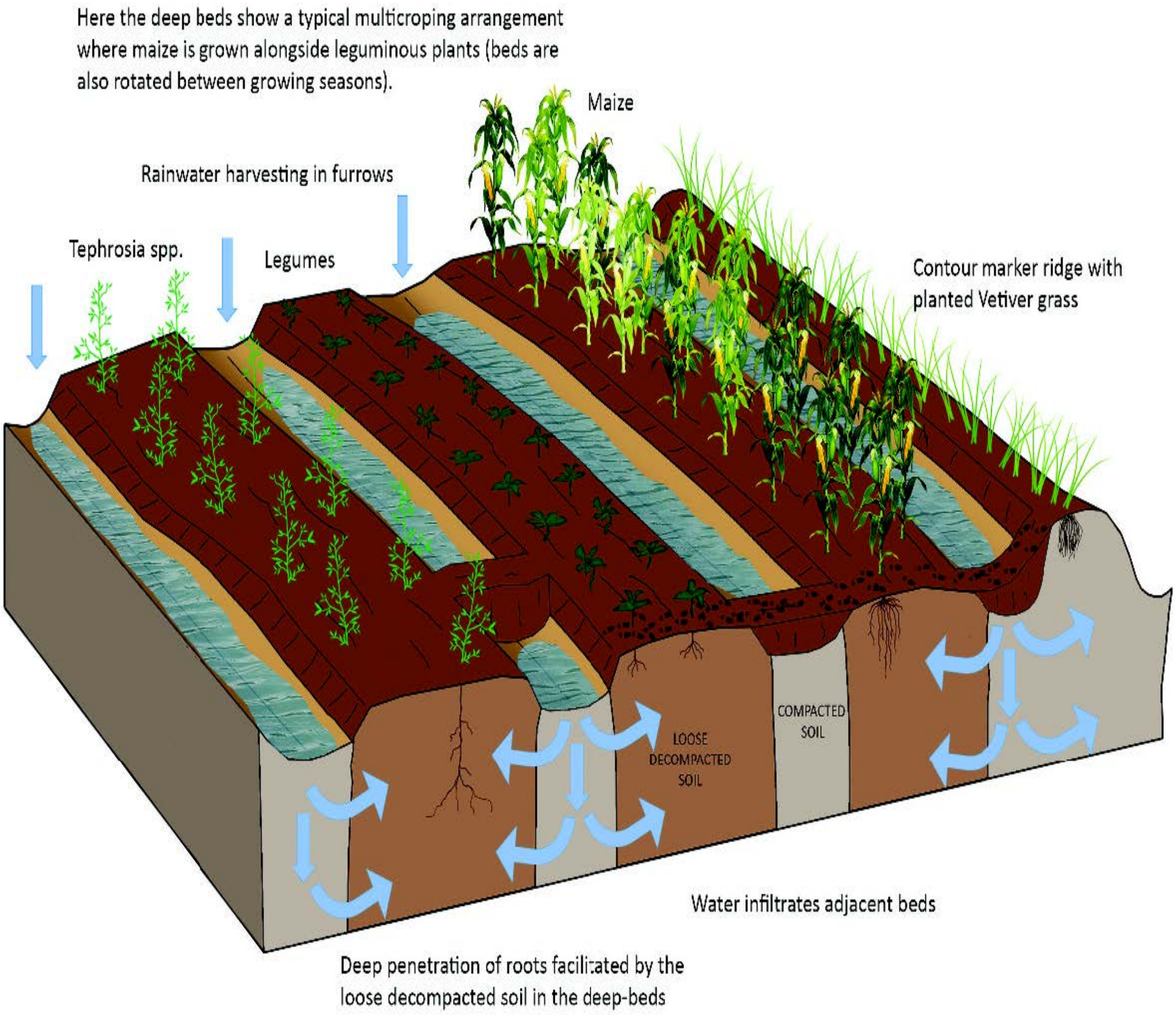


Figure 1.1 Illustrated deep-bed system (Dixon et al., 2017).

Deep tillage is followed by constructing raised contour ridges at a zero gradient across a plot spaced according to the physical terrain of the land. These contours become marker ridges which guide the orientation of the one metre (1m) wide raised seed beds (Figure 1.1). The making of these raised seed beds creates furrows between beds and at the end of each plot. Box ridges are then constructed in the furrows in an alternating fashion across the plot while the edges of the plot are closed with raised ridges to further contain and harvest rainwater for crop use during dry spells and to reduce accumulation of rainwater to prevent soil erosion during or after heavy rainstorms (Mvula & Dixon, 2020). Contour ridges are planted with reinforcement grasses like *Vetiveria zizanioides* (vetiver grass), *Tephrosia vogelii* (tephrosia) or Lemongrass (*Cymbopogon citrus*) which deliver multiple benefits such as addition of organic matter and animal fodder (vetiver grass), natural pesticides (tephrosia) and made into spices or beverage (lemongrass) (Thierfelder et al., 2017). To maintain an improved soil physical structure, the improved raised beds are covered by crop residues and cover crops like pumpkins (*Cucurbita sp*.) while walking on bed surfaces by people or livestock is prohibited. These interventions are meant to avoid soil desiccation through direct sunlight on bed surfaces or re-compaction by physical force besides improving the soil's ability to buffer temperature fluctuations that regulate moisture availability and seed germination (Steward et al., 2018).

In the subsequent years, the need for tillage is eliminated to limit mechanical disturbance of the improved soil conditions while cover crops are encouraged to reduce weed growth. Farmers are also urged to practice maize-legume intercropping and crop rotation, either across space (different crops on different plots) or time (one year to the next) (Silberg et al., 2017). Moreover, the decomposition of crop residues is a key source of organic matter and helps create conducive conditions for microbial activities which improve soil porosity and replenish soil nutrients. These combined form key components of a resilient soil ecosystem that support and sustain food production (Shaxson et al., 2014). Additionally, farmers are trained to make organic manure like *Bokashi, Changu, Mbeya* and compost using locally available raw materials (Zant, 2014; Mvula & Dixon, 2020). These locally made organic inputs have proven effectiveness among smallholder farmers in the SSA as well as Asia (Xiaohou et al., 2008; Zant, 2014). This is particularly important in Malawi given that most farmers cannot afford pricey inorganic fertilizers to correct for lost nutrients and boost crop productivity (Vanlauwe et al., 2014b).

Figure 1.2 The Tiyeni decentralised demonstration garden (Dixon et al (2017))

Tiyeni takes on demand-response extension system where it provides DBF training upon request from a group of farmers (Mvula & Dixon, 2020). By 2017, Tiyeni moved from its originally centralised demonstration garden system to a decentralised system where farmer-to-farmer extension sessions rotate from one farmer to the next (see Figure 1.2) in a drive to facilitate integration of the DBF into existing farmers' cropping systems. As a prevalent practice among NGOs in the agricultural sector, Tiyeni's extension work incorporates the provision of free inputs 1kg of maize, beans (*Phaseolus vulgaris*), soya beans (*Glycine max*), groundnuts (*Arachis hypoaea*), and bambara nuts (*Vigna subterranea*), 5kg of Urea and NPK inorganic fertilizers, line level (for lead farmers), wheelbarrow, hand hoes and pickaxes. In addition, the organisation runs a livestock pass-on programme which comes as awards for best performing farmers.

According to Gondwe (2018), farmers who have practised the DBF have experienced multiple benefits ranging from improved root growth, increased rainwater infiltration, reduced soil erosion and improved soil fertility through application of manure and incorporation of crop residues. As a result, anecdotal evidence shows that farmers often get double yields relative to CR plots with others reporting of significant increases in their household food availability after practising DBF. As word of Tiyeni's successful technology spreads, demand for DBF trainings has surpassed the organisation's capacity and resources. Identical to CA proponents, Tiyeni considers its DBF technology as panacea to Malawi's food and poverty challenges. Sections 1.3 and 1.4 however, highlight the importance of considering these issues through the lens of social-ecological systems given their complexity at various levels. Knowledge gaps exist, therefore, about DBF's site-specific effectiveness that considers the uniqueness of place, how this influences extent to which the DBF contributes to win-win situations and the technology's long-term sustainability.

1.6 Aims and objectives

This study, therefore, seeks to answer these questions and in particular the fundamental issue of whether the DBF represents a social-ecologically sustainable way of addressing food and livelihood security issues in Malawi. This question is broken down into four specific objectives as follows:

1. Analyse the environmental impacts of DBF and its environmental sustainability, particularly:
    a. Assess impacts of the DBF on soil and water quality and the resilience of the local environmental systems.
    b. Assess maize yield response to changes in soil and water quality

2. Examine DBF's impacts on and its contributions to farmers' livelihoods sustainability and adaptive capacity, particularly:
    a. Assess its impacts on household food security, farm labour demand and income.

    b. Assess its contributions towards farmers' adaptive capacity and their resilience to social and ecological changes.

3. Examine DBF's institutional sustainability and how it integrates with existing local institutions in which it is practised, particularly, the research will:
    a. Identify the extent to which Tiyeni's extension approach contributes to farmers' social capital.
    b. Explore different ways of improving Tiyeni's extension approach for the enhancement of farmers' human and social capital.

4. Explore ways to improve DBF's effectiveness to suit various social-ecological scenarios. Specifically:
    a. Identify and analyse adaptations and modifications farmers make to the DBF and how these can be co-developed for site-specific adoption.
    b. Explore the extent and impacts of Tiyeni's support towards smallholder farmers' innovations and experimentation towards building resilient farm systems and local livelihoods.

1.7 Thesis outline

This thesis comprises a total of ten chapters. Chapter 2 provides an understanding of the current knowledge about various forms of CA and gives in-depth analysis of existing knowledge gaps. Chapter 3 justifies selection of the methodology, theoretical basis and Participatory Learning and Action (PLA) which inform the choice of data collection methods. This is proceeded by Chapter 4, describing study sites and individual participants (farmers) that contextualise results in the subsequent chapters. Chapter 5 presents the environmental side of the story, focusing on objectives 1a and 1b using on-farm evaluation and monitoring of the impacts of the DBF on soil and water dynamics, merging this with farmers' lived experiences and observations that triangulate the former. Figure 1.3 illustrates how these chapters link to each other.

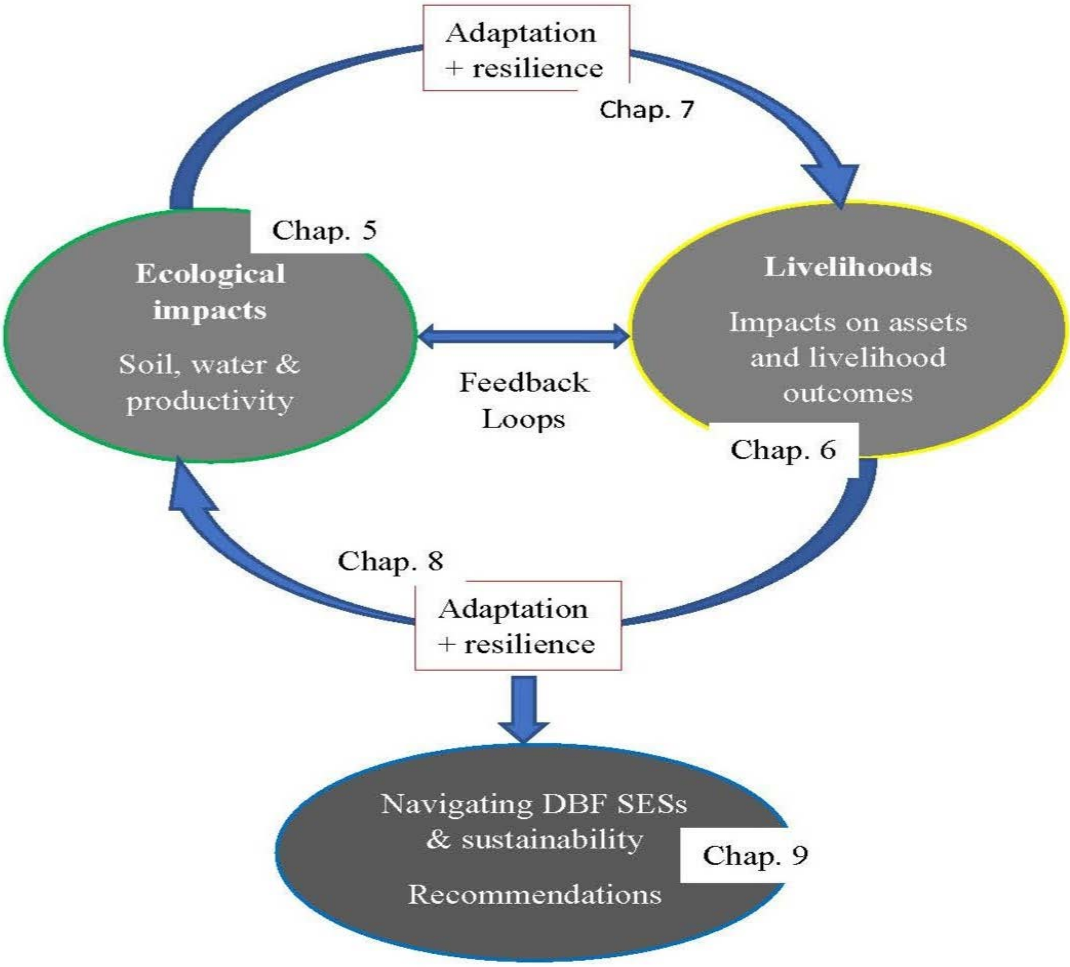


Figure 1.3 Results chapters and how they relate with each other.

Chapter 6 is about livelihood outcomes of the DBF which are linked back to Chapter 5 through objectives 2a and 2b; short term and long-term impacts of the DBF on farmers livelihoods outcomes. This draws on the Sustainable Livelihoods Framework (SLF) and PLA as the principal analytical and data collection approaches, respectively. Chapter 7 focuses on impacts of Tiyeni’s extension system on farmers’ social capital and local institutions as supporting structures (objectives 3a and 3b) using Social Networks Analysis (SNA) for the integration, adaptation, and re-innovation of the DBF technology into farmers’ site-specific social-ecological conditions. This chapter is inseparably connected to Chapter 8 which provides an analysis of farmers’ adaptation and re-innovation of DBF through local experimentation (objectives 4a and 4b).

Together, Chapters 7 and 8 tell the story of how farmers adapt and re-innovate the DBF to both respond to current and future social-ecological challenges which contribute to building of resilient and sustainable farming systems. Chapter 9 merges key findings from Chapters 5 through 8; synthesising emerging patterns and trends that explain and encapsulates key social-ecological findings and the sustainability of the Tiyeni's DBF conservation agriculture in northern Malawi. Chapter 10 concludes the thesis by highlighting key messages and lessons to inform future CA and DBF practices and need for further research.

Chapter 2

Conservation Agriculture in Sub Saharan Africa

Chapter overview

Before examining the large body of CA literature, a brief overview of the global food security challenges, its history and its relevance in studying CA and the deep bed farming system is presented. The CA sub-section discusses existing CA knowledge in Sub Saharan Africa (SSA) with respect to smallholder farmers, connecting this to the deep bed farming system as the focus of this investigation. This chapter ends by summing up significant knowledge gaps in CA, aims and objectives of this investigative work before moving on to chapter three that discusses the adoption of social-ecological approaches, the methodology and methods.

2.1 Food security in a changing world

As the world races against time to achieve the 17 Sustainable Development Goals (SDGs), hunger and malnutrition remain the greatest challenges in history. Despite a 300 million reduction in the number of hungry people between 1990 to 2019, over 690 million individuals (8.9% of world population) still sleep on an empty stomach (FAO et al., 2020; WFP, 2021). More so, the last five years has seen a 60 million yearly increase in the number of hungry people around the world, negating the previous achievements in hunger reduction (FAO et al., 2020). Recent projections show that over 840 million individuals will be facing serious food shortages by the year 2030 (FAO et al., 2020) making it urgent to rethink farming systems to reflect current needs. As the world experiences unprecedented threats to food production owing to the increasing pressure of population growth on land resources as well as catastrophic impacts of climate change, the need for sustainable forms of food production has never been more urgent. Attaining food security for the burgeoning world population therefore requires drastic and holistic innovations that consider both social and environmental challenges that determine and influence production, availability, affordability, and quality of food. FAO (2006: p.1) defined food security as:

> “*Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices*”.

Focusing on only the supply side, this definition was limited in scope given that other extenuating factors can cause significant disruptions to food supply. For instance, demand for specific quality of food, political stability, financial stability and natural disasters can radically render food inaccessible (Sen, 1981). Conversely, the 1986 World Bank report on Poverty and Hunger (Clay, 2002) defined food security by focusing on issues that lead to food insecurity.

> *“a situation where there is limited or uncertain availability of nutritionally adequate and safe foods or limited or inability to access and acquire acceptable foods in socially acceptable ways”*
>
> (World Bank, 1986: p. 2)

Two major forms of food insecurities emerge from this school of thought: chronic and transitory food insecurities (Clay, 2002). Transitory food insecurity happens where food availability and access are compromised by incidents of natural disasters, economic depression, or conflicts (World Bank report as cited by Clay, 2002). Chronic food insecurity is where poor income and high levels of poverty become barriers to food security. This is the most common form of food insecurity across the Sub-Saharan Africa (SSA) (Giller, 2020; FAO, 2020).

In Southern African countries, chronic food insecurity is found to be rooted in complex and inter-related social-ecological conditions such rapid population growth which often leads to land fragmentation, continuous monocropping and high soil fertility degradation rates as well as increasing water stresses as climate change tightens its grip (Krugman, 2012; Porter et al., 2014; Niang et al., 2014; van Ittersum et al., 2016). Climate change has been predicted to bring more pressure on food production systems across the world with increasing number of extreme events such as heavy rainfall, droughts, heatwaves, pests, and diseases (Krugman, 2012). Negative impacts are expected to be more evident in regions where many people do not have alternative livelihood activities apart from farming (Brown & Funk, 2008) and SSA is projected to suffer the most with its ever-increasing population, with the need to double food supply, water and livestock by the year 2050 (Porter et al., 2014; UN, 2017; FAO, 2020). The 5th IPCC Report predicts that if current greenhouse gas emission scenarios persist, global temperatures will rise by 2.75^0C by the year 2030, leading to significant negative impacts on rainfall regimes across the world with serious impacts on food security (Porter et al., 2014).

2.1.2 Availability and access to food

In SSA, food security for millions of smallholder farmers is determined by the availability of food through their own production or access through distribution and exchange (Gregory et al., 2005; Porter et al., 2014; FAO et al., 2020). Consequently, failure to produce enough food for one’s household implies dependence on external sources through purchases or relief initiatives where natural disasters are involved (Mloza-Banda et al., 2016). Land ownership issues, agroecological factors, policy environment and market fluctuations are all pertinent factors determining the level of food production and whether a household is food secure or not (FAO, 1997; Gregory et al., 2005; Giller, 2020). On the other hand, access is about affordability and allocation of food including household and individual preferences of food (Gregory et al., 2005).

While inadequate production is the major reason for food insecurity in SSA, literature indicates access to food due to poverty and unconducive policies equally derails elimination of hunger at a global scale (FAO et al., 2020; 2015). Poverty limits people’s access to food and thus increases their vulnerability (Ecker & Breisinger, 2012) since households may lack enough income to purchase food (also known as economic food access) or lack sufficient land and resources to produce their own food (FAO, 1997; Garrett & Ruel, 1999). This is the reason food security is closely linked to poverty alleviation in humanitarian projects across Africa. Food must be enough to meet one’s metabolic requirements and safe for healthy lives (Gregory et al., 2005; Ecker & Breisinger, 2012). Food stability is the ability to get food over time, whether food insecurity comes in the form of chronic food shortages or transitory (FAO, 1997).

According to NSO (2018), 84% of Malawian population comprises subsistence smallholder farmers (Mloza-Banda et al., 2016; NSO, 2018). FAO (2006) and USDA (2018) define household food security as that situation where all members of the family always have access to enough food for an active and healthy life and where none of the members live under the threat of hunger or starvation. Under the backdrop of consistently poor crop productivity on smallholder farms across SSA despite decades of development and promotion of sustainable forms of food production (Tittonell & Giller, 2013; Abate et al., 2015; Giller, 2020), feeding the growing population under changing climate will require rethinking current agricultural techniques to make them more adaptive and sustainable.

2.2 Conservation agriculture: a new panacea for food insecurity?

2.2.1 Origins: The American dust bowl

Conservation agriculture originated in the Americas (Brazil and United States of America) on large highly mechanised commercial farms where extensive tillage was attributed to causing the American Dust Bowl in the 1930s (Giller et al., 2009; Andersson & D’Souza, 2014). Correspondingly, the need to cut down on costs of fossil fuels as well as emission of greenhouse gases (GHGs) from the heavy machinery prompted many farmers to consider what was formerly called conservation tillage that aimed at minimising tillage activities (Hobbs, 2007). Furthermore, the use of herbicides on such farms made it possible to effectively control weed infestation that arose from the lack of tillage (Giller et al., 2009). For such large-scale farmers, their main objective was never to increase crop productivity. Rather, they wanted to reduce their farm operational costs as well as associate their products with sustainability (Bolliger et al., 2006). Indeed, reduced crop production costs was the main benefit from this before researchers and development organisations took interest to promote it in Africa and Asian countries (Andersson & D’Souza, 2014).

Since the 1990s, conservation tillage, now called CA has undergone extensive research and development that has helped in refining and redefining it as a distinct package of agricultural practices that purport to be sustainable. Realising the need to halt soil degradation due to continuous nutrient uptake and to reverse high levels of GHGs from farm machinery, retention of crop biomass on the soil surface as well as diversification and rotation of crops at a farm level were encouraged. Over time, soil fertility improvements were observed which translated to improved availability of crop nutrients to increase crop productivity across these large farms, providing them with win-win situations (Kassam et al., 2009). To date, CA is defined as:

> *"…an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment"*
>
> FAO, 2008; p. 1).

At the centre of the technology are the three principles of minimum or reduced tillage, permanent organic soil cover, and crop diversification and rotation (Baudron et al., 2007). The practices associated with these three CA principles are diverse in nature and dependent on various social and ecological factors. In theory, CA has been considered a suitable technology that could be adapted to specific social and environmental conditions that would help facilitate farm system resilience and sustainability (Thierfelder & Wall, 2009; Ngwira et al., 2014). But despite lessons from the Green Revolution, CA has been and continues to be practised as a rigid blueprint based on positivist off-farm research and results based on commercial and mechanised farmers elsewhere. Until the influential papers by Giller et al (2009) and Andersson and D'Souza (2014), boosting CA adoption across Africa that disregarded uniqueness of place was the focus of both research institutions and NGOs. Consequently, research centred around generation of evidence to support the promotion of CA without considering its suitability and effectiveness among resource-poor smallholder farmers in SSA.

Minimum tillage is based on a consensus that continuous mechanical soil disturbance during ploughing and seeding leaves soils prone to destructive raindrops and runoff while causing formation of compacted soil layers below the cultivated zones (hardpans) (Trapnell, 1942; Shaxson et., 1997; Hobbs, 2007; Kassam et al., 2009; Shaxson et al., 2014; Njoloma et al., 2016). It is argued that the latter reduces water infiltration and increases runoff as water accumulates during a rainfall event. Coupled with continuous monocropping, tillage has further been linked to the depletion of soil organic matter, increased carbon oxidisation and release of GHGs, contributing to global warming and climate change besides rendering agricultural soil unproductive (Kassam et al., 2009; Thierfelder & Wall, 2009; Thierfelder et al., 2014; Njoloma et al., 2016). While it is widely acknowledged that tillage is an important activity that helps control weed infestation (Giller et al., 2009), the minimum tillage principle has seen significant shift from the previous version of simply reducing tillage extent and frequency to the elimination altogether (Thierfelder et al., 2005; Kassam et al., 2009; Thierfelder et al., 2017; Asfaw et al., 2018). Despite the shift from minimum to no-tillage (no-till), research aiming at understanding which principle contributes to which CA benefits indicate that elimination of tillage only helps reduce labour demand associated with tillage activities, but does not improve soil fertility, reduce soil erosion, or increase crop productivity without crop residue retention, use of herbicides and inorganic fertilizers (Rusinamhodzi et al., 2011; Kirkegaard et al., 2014a; Andersson & D'Souza, 2014). Section 2.3 reviews this body of literature to situate the place of tillage or no-till pertaining to smallholder farmers in SSA.

The principle of permanent organic cover has been practised in many countries with proven soil and water conservation benefits long before its association with CA (Knorr, 2005; DeAngelis, 2013; Nkomwa et al., 2014). In CA, this practice entails retaining crop residues on soil surfaces after harvesting as well as use of green plants and green manure (Kassam et al., 2009) for multiple benefits. A consistent and long-term practice has been found to contribute to many published CA benefits, ranging from soil fertility improvement, soil erosion control and reduction, regulation of soil micro-temperatures, enhanced soil ecosystems and productivity and gradual increases in crop yields among others (Stevenson et al., 2014; Kassam et al., 2014; Giller et al., 2014; Pittelkow et al., 2015b). Despite its pivotal role in CA, crop residue retention in many African countries remains problematic and complex.

Considering the rising risks of crop failure owing to various ecological shocks and pressures, the third principle concerns itself with the promotion of crop diversification, rotation and intercropping (Shetto and Owenya, 2007; Kaumbutho and Kienzle, 2007; Thierfelder et al., 2014). Crop diversification is a vital component of resilient agricultural systems as it provides farmers with a fallback option should their main crop fail (Hobbs, 2007; Mloza-Banda & Nanthambwe, 2010). Similarly, temporal, and spatial crop rotation and intercropping have been promoted as part of CA as a way of preventing crop failure due to pests and diseases (Thierfelder et al., 2014; Kassam et al., 2017). As with other two principles, crop rotation and diversification has seen little success in many countries due to mismatches unique to communities and individual farmers (Bolliger et al., 2006; Ragasa, 2017; Silberg et al., 2017). Constraints and issues with the implementation and upscaling of these three principles have been widely acknowledged as contributing to the limited uptake of CA practices particularly in SSA where every rural development project contains an element of conservation agriculture.

2.2.2 Global adoption trends

CA adoption studies remain contentious as well as confusing due to lack of consolidated data across countries, consensus on what is considered adoption as well as what constitutes CA (Andersson & D’Souza, 2014; Chinseu et al., 2019). Furthermore, questions arise pertaining to whether incentivised uptake as part of CA promotion project participation counts as adoption (some in-country reports and NGOs include these figures). Correspondingly, literature on CA adoption remains silent on cases of dis-adoption with recent publications drawing attention to understanding why farmers abandon CA practices in order to better grasp the depth of challenges surrounding CA adoption.

The past decade has seen tremendous interest in the promotion of CA practices across the world that has increased land coverage under CA from 106 million hectares in 2009 (7.5% of global cropland) to some 180 million hectares by 2016 (12.5% of global cropland), representing a 69% increase (Kassam et al., 2009; Kassam et al., 2017a; Kassam et al., 2019). Kassam et al. (2019) attribute this to the technology’s ability to offer multiple benefits in terms of farm productivity and economic returns. It is also noted that despite this sharp increase in a space of 7 years, increased extent of CA cropland has been confined to large-scale commercial farms in North and South America and Australia (Kassam et al., 2019). According to Kassam et al. (2019), 38.7%, 35% and 12.6% of all CA farms are in South America, North America and Australia respectively. On the other hand, Europe, Asia and Africa account for only 5%, 7.7%, and 1.1% of the global CA cropland respectively while Russia and Ukraine collectively account for 3.6%. Despite so much interest in CA practices from numerous international local development partners, CA adoption in Africa remains slow/low.

A parallel study looking at dis-adoption in Malawi suggests widespread abandonment of CA practices among smallholder farmers due to a plethora of challenges they face and their inability to sustain the practice without external help (Chinseu et al., 2019). While Kassam et al. (2019) claim exponential CA adoption among smallholder farmers, evidence from across SSA show the opposite (Corbeels et al., 2014; Mazvimavi, 2016). Contrary to what CA proponents advance (Kassam et al., 2012; Thierfelder et al., 2016; Kassam et al., 2017a), crop yield increments have largely remained low with other farmers experiencing reduced yields that ultimately make them food insecure (Pannell et al., 2014; Baudron et al., 2015; Chinseu et al., 2019). The mismatch between farmers' immediate food needs and CA's inability to meet them is perhaps one of the key factors that has rendered CA less attractive in SSA. Despite funding and training support from major donors and international organisations such as FAO, AfDB, IFAD, CIMMYT, NEPAD among others (Kassam et al., 2019), dis-adoption of CA practices among smallholder farmers at the end of incentivised promotion projects points to CA's failure to meet farmers expectations (Chinseu et al., 2019).

According to a dis-adoption study by Chinseu et al (2019), Malawian smallholder farmers have reported numerous challenges associated with elimination of tillage, crop residues, increased investment requirements, labour challenges as well as complex situations that arise due to provision of incentives and lack of it. Correspondingly, lack of effective and continuous farmer consultations and learning and a focus on technology diffusion to attract project participants are argued to be the major reasons why CA adoption remains poor. Under this backdrop, the ability of this technology to make a sustainable contribution to resilient agricultural livelihoods among smallholder farmers is unclear. In a review of CA projects across SSA, Corbeels et al. (2014) conclude that much of the existing research has been focusing on demonstrating benefits of CA and not how to adapt CA practices to farmers' site-specific needs (p.168). This is the case at a time when evidence suggests that effectiveness of CA practices is questionable under smallholder farming contexts (Giller et al., 2009; Corbeels et al., 2014; Anderson & D'Souza, 2014). Surprisingly, not much attention has been given into further development of CA practices to make such practices relevant for resource poor subsistence farmers in SSA. Farmers are always involved in experimenting, adapting, and re-innovating new farming techniques (Chambers, 1989; Corbeels et al., 2014; Hockett & Richard, 2016) and will only adopt practices that align with their existing production practices and current goals that are mostly short-term rather than long-term.

While existing literature provides us with substantial evidence and reasons why CA adoption has been hindered in SSA, interactions and feedback loops among social and ecological factors that influence the extent, effectiveness and long-term sustainability are still poorly understood. As the adoption theory states (Erenstein, 2002), adoption of new farming technologies will only happen when the farmer in question perceives that benefits of implementing the new technology exceeds its costs or the costs of not implementing something new. For subsistence farmers, it is not only about the claimed CA benefits and incentives that will make them adopt or continue using CA practices, it is about the combination of trade-offs between short-term and long-term benefits, resource constraints, belief systems and local institutions (Tittonell & Giller, 2011; Giller et al., 2011). Unless these place-specific factors are given the attention they deserve, CA practices will remain unattractive among smallholder farmers in SSA.

2.3 CA experiences in Sub-Saharan Africa

2.3.1 Historical perspective

According to Page and Page (1991) and Andersson and D’Souza (2014), minimum tillage agricultural systems have been practised in Southern Africa for decades before a renewed focus on CA developed in the 1990s. The start of what has now been reshaped into conservation agriculture could be traced back to the early colonial times (1920s) where a plough was spontaneously adopted by farmers across the Southern African region (Andersson & D’Souza, 2014). In Malawi, Zambia and Zimbabwe, these systems were mainly introduced on large-scale commercial farms in the 1960s to cut on the ever-rising costs of mechanisation including maintenance of machinery (Smith, 1988; Hagblade & Tembo, 2003a). The interests of these large-scale farmers to cut operational costs resonated with research institutes at that time who were concerned with high levels of soil erosion and such systems (CA related practices) provided the means of reducing soil erosion, especially in Zimbabwe (Andersson & Giller, 2012; Andersson & D'Souza, 2014).

Among the three countries (Malawi, Zambia and Zimbabwe), Zimbabwe was the first country where research both on-station and on-farm about CA technologies started to expand around 1980 (Norton, 1988; Twomlow et al., 1995; Andersson & Giller, 2012). The occurrence of droughts in Zimbabwe in 1980s severely reduced food production and led to widespread increase in poverty levels. These circumstances made soil and water conservation technologies relevant options for researchers and development agents but did not really trigger a change or interest from smallholder farmers whose interest remained immediate food relief (Andersson & Giller, 2012; Andersson & D’Souza, 2014). During the same period, government incentives through input and market subsidies heavily increased crop production in Zimbabwe (Rukuni & Eichar, 1987; Andersson, 2007). These benefits were, however, short-lived due to economic recession that ripped through many essential sectors in Zimbabwe. Such a crisis had substantial impacts on the sustainability of the incentive-based crop increments, leading to high levels of food insecurity and rampant poverty across the country (Andersson & D’Souza, 2014). In 2003, CA technologies were promoted among smallholder farmers through food aid and humanitarian programmes mainly done by donors and international organisations. As documented by Andersson and Giller (2012) and Andersson & D'Souza (2014), this period saw the coming in of a new focus where CA was not only considered a soil and water conservation approach or resource saving for commercial farmers, but also as a way of increasing smallholder food production to reduce food insecurity and poverty (ZCATF, 2009).

In Zambia, high levels of soil erosion and degradation due to prolonged mono-cropping as a result of government policies in prioritising maize production had serious implications for smallholder farmers' food security (Haggblade & Tembo, 2003b; Baudron et al., 2007). In a drive to expand and intensify land use in Zambia, government introduced subsidies and chemical fertilisers including animal traction for smallholder farmers (van Donge, 1984) around 1980 as one way of coping with declining revenues from the copper mines (Goud, 1997; Ferguson, 1999). These subsidies could not be sustained on a long-term basis and were abolished in 1991 (Baudron et al., 2007, p.7). This led to gradual declines in maize yield in the 1990s until droughts and crop diseases made the situation worse, thus leading to serious crop production shocks with significant negative impacts on food security in Zambia (Howard & Mungoma, 1996; Haggblade & Tembo, 2003a; Andersson & D'Souza, 2014).

To a large extent, food insecurity was blamed on poor farming practices (Haggblade & Tembo, 200b, p. 8), making CA more relevant and perhaps the only way out of such problems (Andersson & D'Souza, 2014, p. 118). However, CA was viewed more relevant for farmers involved in highly incentivised cash crop production such as cotton where cotton companies propelled the use of CA practices, with a focus on intensifying crop yield gains, land and labour maximisation and profit margins (Haggblade & Tembo, 2003a; 2003b; Langmead, 2006). By early 2000s, CA promotion was heavily dependent on incentives where provision of seed and fertilisers and implements were common (FAO, 2011b; FAO-OED, 2012; Aune et al., 2012). According to Aune et al. (2012), Andersson & D'Souza (2014), promotion of CA to smallholder farmers could be said to have started in Zambia through provision of incentives to produce cash crops. Despite direct government support in many CA projects in Zambia, the government provided policy that enabled the establishment of the Conservation Farming Unit (CFU) by Zambian National Farmers Union (ZNFU) (Aagard, 2012). This simple historical perspective suggests a similar trend to that of Zimbabwe where CA's introduction was targeted in commercial farms and then trickled down to smallholder farmers through development projects.

Malawi's CA emergence took a different route from that of Zambia and Zimbabwe. The search for better farming systems emerged from the increasing food insecurity and poverty levels among rural population given the high population density, land fragmentation and the resulting soil degradation since 1990s (Mloza-Banda et al., 2016). The need to intensify land productivity as a vehicle to improve household food security and ameliorate poverty provided a fertile ground for the promotion of CA by the international researchers and organisations (van Donge et al., 2001; Ellis et al., 2003; Levy, 2005). To alleviate poverty and improve food security, major development partners such as DFID, FAO, USAID among others partnered with the Malawi government to roll out free input distribution programmes which were attached to farmers' participation in NGO-based livelihood programmes with CA as their major interventions (Ito et al., 2007; Mloza-Banda & Nanthambwe, 2010; Mloza-Banda et al., 2016).

In coordination with international organisations in conjunction with Malawi's Land Resources Conservation Department (LRCD) and the Ministry of Agriculture, the National Conservation Agriculture Task Force (NCATF) was formed to spearhead promotion of CA in Malawi (Mloza-Banda & Nanthambwe, 2010). The first CA initiative in 2000s by Sasakawa Global 2000 (Ito et al., 2007; Mloza-Banda & Nanthambwe, 2010) helped strengthen similar techniques such as correct crop spacing and the use of fertilisers and herbicides through incentive-based programmes to smallholder farmers. From the early initiatives by Sasakawa Global 200, many NGOs, INGOs, research institutes and faith-based organisations have carried out numerous CA projects in Malawi with a drive to transform smallholder farmers' practices and turn around the food insecurity and poverty levels in the rural areas.

Unquestionably, the introduction of CA in SSA provides striking differences that must be revisited to properly understand why it has had little success in these countries despite what proponents claim. Firstly, there exist significant differences in terms of what CA was originally designed for. While it emerged as a fuel saving technique on large, mechanised farms in developed American countries, its promotion in these poverty-stricken nations was based on increasing crop productivity as a rural development tool. Furthermore, promoting agencies largely ignored the obvious differences among large-scale commercial farmers with disposable income to invest in CA unlike resource poor smallholder farmers in these countries whose immediate concern is finding their next meal. Similarly, proponents have largely focused on increasing the number of CA project participants and adopters, ignoring the urgent need to tailor the technology according to farmer and site-specific uniqueness. Common in all three countries is the apparent use of input incentives attached to these CA promotion project amidst exaggerated promises of what the new technology offers to attract more participants. Coupled with top-down technology transfer characterising these projects, suitability, appropriateness, effectiveness, and long-term sustainability of CA practices across SSA remain problematic.

2.3.2 Current CA practices in SSA

CA practices in SSA fall into two categories; manual among smallholder farmers and semi-mechanised among middle to large-scale farmers (Umar et al., 2011; Ngwira et al., 2014; Mzvimavi, 2016; Thierfelder et al., 2018). Leading manual practices under CA in SSA include zero tillage, direct seeding and agroforestry practices and digging of planting basins where other additional aspects of CA are applied (Kassam et al., 2009; Concern Universal, 2011; Mazvimavi, 2016). Where these practices are promoted, farmers are also encouraged to cover their soils with mulch, usually with crop residues (Wall, 2007; Thierfelder & Wall, 2009; Nkala, 2012). Further, farmers are taught to include crop rotation with legumes, both in space and time, to help with nutrient fixing, regulation of soil temperatures, pests and disease control and as a way to diversify crop production systems to make them resilient to shocks and climatic stressors (Andersson & Giller, 2012; Steward et al., 2018). Against a strong advocacy for a prescriptive CA blueprint for maximum benefits (Baudron et al., 2007; Hobbs, 2007; Kassam et al., 2009), various forms of CA practices exist that either make use of one or only two of the CA principles (Nkala, 2012; Mloza-Banda et al., 2016; Thierfelder et al., 2018). This is a strong suggestion that the rigid one-size-fits-all CA experts advance require drastic adaptation and modification if any efforts in promoting them are to leave lasting positive changes among poor smallholder farmers in countries like Malawi.

While in theory CA lends itself as a technology that can be adapted to site-specific needs for improved crop yields, and soil conservation (Kassam et al., 2009; FAO, 2010; Steward et al., 2018), evidence suggest that its promotion takes a prescriptive and top-down approach (Giller et al., 2014; Halbrendt et al., 2014; Giller et al., 2015). Despite recognising the need for adaptation and a bottom-up approach (Thierfelder et al., 2017), there is limited evidence to indicate attempts to support on-farm farmers' experiments and modifications (Hockett & Richard, 2016). The next sections argue that this failure to recognise uniqueness of places and individual farmers is the major reason for the apparent failure of CA initiatives in SSA.

2.4 Emerging issues: claims and evidence in SSA.

2.4.1 Basis for CA promotion in SSA

The promotion and advocacy of CA across the SSA region has been based on its proposed ability to provide sustainable benefits in terms of farmers' livelihoods and the environment. These benefits have been linked to experiences on controlled on-station experiments as well as from large-scale and mechanised farms in America (Kassam et al., 2009; Giller et al., 2009; Andersson & D'Souza, 2014). Because crop residues and green weeds are left to decompose on undisturbed soil surfaces, the soil ecosystems improve due to the addition of organic matter (Kassam et al., 2009). With a consistent practise for a long period of time, normally more than five years, the soils regain fertility, improve on porosity as well as soil microbial activities. Such combinations help improve rainwater infiltration to reduce surface runoff and erosion, improve soil productivity and help sustain or slightly improve crop yields where herbicides, inorganic fertilizers are used (Bescansa et al., 2006; Andersson & Giller, 2012; Mazvimavi, 2016). Assuming soils remain undisturbed, and residues are consistently retained, soil conditions become closer to natural forest surfaces where they are able to sequester carbon and reduce GHGs from agricultural lands (Bolliger et al., 2006; Derpsch, 2007), thus acting as important carbon sinks while also sustaining food production for farmers (Thierfelder et al., 2016). Moreover, improved rainwater infiltration is a vital component of resilient cropping systems given the increased frequencies of climate-related shocks and pressures such as dry spells and droughts (Simelton et al., 2013; Steward et al., 2018). The latter is particularly critical in semi-arid regions where moisture availability draws the line between food security and food insecurity (Kassam et al., 2009; Porter et al., 2014; Steward et al., 2018).

The promotion of CA in SSA has been based on the above experiences from commercial and mechanised farms in developed world, expecting the same results in poverty-stricken countries like Malawi where most farmers live below the poverty line (less than US$1 per day) with completely different agroecological conditions (Andersson & D’Souza, 2014; Giller et al., 2015). Unsurprisingly, evidence of CA’s effectiveness in SSA as well as other regions remain inconclusive and contradictory with numerous challenges that resource poor farmers face as they try to practice it on their own (Pannell et al., 2014; Corbeels et al., 2014; Mazvimavi, 2016; Chinseu et al., 2019). According to Chinseu et al. (2019), most dis-adopters of CA in Malawi have cited the lack of soil and water conservation and yield increment benefits as promised by CA proponents. This next section discusses these to highlight specific knowledge gaps that the later chapters address through studying the DBF.

2.4.2 Soil and water conservation benefits

Contrary to what has been theorised as benefits of no-till for the smallholder farmers, literature suggests no-till without proper mulching is disastrous for resource poor farmers which explains the poor adoption rates and dis-adoption across SSA and Africa in general (Andersson & D’souza, 2014; Chinseu et al., 2019). The practise of no-till alone may lead to a number of problems such as soil crusting, reduced infiltration, increased evaporation, escalated soil erosion, reduced available soil moisture, increased weed infestation that lead to labour bottlenecks, poor crop germination and consequently reduced crop yields and increased vulnerability of smallholder farmers to climate change impacts, food insecurity, and recycled poverty (Giller et al., 2009; Govaerts et al., 2009; Mupangwa et al., 2012; Mazvimavi, 2016; Chinseu et al., 2019). Improvements in the soil structure such as soil macropores, soil moisture, increased soil carbon and soil organic matter are brought about mainly by the retention of crop residues and not because of no-till or reduced tillage as commonly advertised (Corbeels et al., 2006; Farage et al., 2007; Kassam et al., 2009). CA benefits manifest themselves after a long period of use, usually after five or even ten years or more of consistent use (Giller et al., 2009; Ngwira et al., 2012; Ngwira et al., 2014;) against the farmers' short-term needs. Seeing that CA's benefits mainly accrue from consistent and long-term crop residue retention, it is surprising that elimination of tillage has become a central part of CA (Asfaw et al., 2018).

Part of the problem with existing CA practices in SSA arises from practising reduced or no-till on the same compacted and degraded soils after years of hand hoe tillage. In SSA, use of hand hoes in the remaking of seed beds remains a dominant form of crop cultivation (Mloza-Banda et al., 2016; Thierfelder et al., 2016). Farmers are encouraged not to till their compacted soils because crop residue retention is expected to improve the soil' physical and biochemical conditions in the long-run, normally after five years (Giller et al., 2015). What is clear from this is that farmers' immediate needs are ignored for the sake of CA's long-term expected benefits. The problem gets complex when crop residue challenges in SSA are considered. It is well recognised that keeping crop residues in Malawi and other neighbouring countries faces challenges ranging from insufficient availability, multiple use of these resources as well as trade-offs arising in crop-livestock mixed farming systems (Erenstein et al., 2012; Andersson & D'Souza, 2014; Steward et al., 2018). It should not be surprising therefore that CA's soil improvements take more than five years to accrue. Surprisingly, development agencies, researchers and academic institutions have not moved beyond advancing CA adoption among smallholder farmers to reconsidering the CA package itself and how it can be adapted for these farmers.

Even where livestock is not part of the agricultural system, low biomass production in smallholder farmers' fields limits the application of permanent soil cover (Erenstiene, 2002; Giller et al., 2009; Rufino et al., 2011; Ngwira et al., 2014). Such situations arguably hinder the effectiveness of CA in reducing runoff and soil erosion in smallholder farmers' own fields away from scientifically managed plots. According to Wortmann et al. (2010), USDA-Natural Resources Conservation Service (2010) and Giller et al. (2014), continuous use of no-till alone will eventually result in soil surface sealing and compaction and thus further reduce water infiltration, increase runoff and accelerate soil erosion by water. Where mulching is limited as is the case in many SSA countries, it is recommended therefore to consider strategic tillage to improve and loosen the soil profile to encourage water infiltration and reduce surface runoff and soil erosion (Aina et al., 1991; Giller et al., 2009; USDA-Natural Resources Conservation Service, 2010; Wortmann et al., 2020; Giller et al., 2015). With the current focus on no-till, there is limited, if any information about the effect of strategic tillage combined with crop residue retention and physical structures on surface runoff, water infiltration and soil erosion.

According to Roose & Barthes (2001), Andersson & D'Souza (2014) and Giller et al. (2015), one of the undisputed benefits of CA is reduced runoff and soil erosion. In two different studies that attempted to differentiate soil erosion reduction effect of CA from no-till and mulching, Guto et al. (2011) and Baudron et al. (2012) found that practising no-till without mulching is disastrous and leads to sealing of soil surface, accumulation of runoff and increased soil erosion. Further, reduced soil erosion benefits in CA fields have been reported to be more pronounced in areas with less erodible soils and undulating terrain (Lal, 1998a; Roose and Barthes, 2001). However, such benefits are limited. Roose and Barthes (2001) noted that where the land is very steep, mulching alone becomes a weak approach to reducing soil erosion and thus suggests other physical structures such as contour ridges and box ridges that would help capture rainwater, reduce water accumulation and runoff, consequently reducing soil erosion and degradation. Given challenges surrounding crop residue retention in SSA, CA's impacts in improving rainwater infiltration, reducing surface runoff and soil erosion on relatively flat land remain limited.

Where crop residue retention or mulching is involved, it has been reported that CA improves rainwater use efficiency through an improved water infiltration with reduced evaporation from the soil surface (Theirfelder & Wall, 2009). This improvement comes along with a reduced runoff and soil loss (Theirfelder & Wall, 2009; Njoloma et al., 2016). In a two-year experiment in Zimbabwe and Zambia by Theirfelder and Wall (2009), CA plots registered an increased infiltration of over 45% greater than conventional tillage system in Zimbabwe while it was found to be more than 55% in Zambia (Theirfelder & Wall, 2009, p. 217). Roth et al. (1988) and Theirfelder et al. (2005) link the increased infiltration and soil moisture in CA fields to the increasing amount of organic matter, improved microbial activities, reduced disturbance of soil pore system and root penetration in the soils under CA which usually takes long time to manifest themselves. A key point once again is that these are results from well designed and controlled experiments, rather than under resource poor farmers' conditions.

2.4.3 Organic matter, carbon, Soil pH and Soil bulk density

Despite CA being linked to an increased amount of organic matter, soil carbon and reduced soil bulk density, empirical evidence from literature provide mixed observations and make such claims inconclusive and arguably based on optimistic thinking. Many have considered no-till as being able to sequester soil organic carbon, organic matter and consequently reduce soil bulk density with improved soil structure (Lal, 2007; Kassam et al., 2009). According to UNEP (2013), replacing conventional tillage systems with no-till CA systems results in increased soil organic matter, soil carbon sequestration and hence contributing to mitigation of climate change, improved soil quality for improved crop growth and yields. While no-till resulted in increased soil organic carbon and soil organic matter and decreased soil bulk densities elsewhere, there is an increasing volume of evidence from on-farm field experiments that show inconclusiveness and variance of such reports and claims (Baker et al., 2007; Chivenge et al., 2007; Govaerts et al., 2009; Luo et al., 2010; Chan et al., 2011; Paul et al., 2013).

Due to limited soil mixing as a result of no-till, soil organic matter and soil carbon stocks appear to increase, consequently decreasing bulk density in the first 5 cm of the soil profile while the rest of the soil profile remains the same as in CR (Powlson & Jenkinson, 1981; VandenBygaard & Kay, 2004; Powlson et al., 2014). Apart from lack of organic matter mixing in the soil profile, limited crop residue incorporation with its consequent soil erosion and insufficient levels of nitrogen (N), phosphorus (P) and sulphur (S) in smallholder farmers' fields further limit no-till's ability to sequester and accumulate soil organic carbon (Scopel et al., 2005; Giller et al., 2014; Richardson et al., 2014). In cases where there are sufficient crop residues to be retained in the soils, Rusinamhodzi et al. (2011) provides evidence that long term soil organic matter carbon accumulation may lead to water logging in no-till systems which would then negatively affect crop growth and reduce yields and CA's profitability.

Widespread assertions that a shift to no-till will lead to soil carbon stock accumulation and thus provide climate change mitigation alternative in agricultural systems (Lal, 2004; 2011; 2013; Kassam et al., 2009; World Bank, 2012; UNEP, 2013) remain contentious. In a long-term tillage system experiment in France, Dimassi et al. (2014) reported no increase in soil organic carbon stock after 41 years of consistent practise. Similar results have been reported by several authors including VandenBygaard et al. (2003), Baker et al. (2007), Govaerts et al. (2009), Luo et al. (2010), Nyamangara et al. (2013) and Powlson et al. (2014). According to Powlson et al. (2016), no-till leads to emissions of nitrous oxides that further determine soil carbon stocks and its contribution to climate change mitigation. These gases are 298 times more potent as greenhouse gases than carbon dioxide (CO_2) and a small amount of these gases can strip off any CO_2 benefit which no-till is claimed to provide (IPCC Report, 2007). Surprisingly, the prescriptive promotion of CA in SSA appear to ignore this side of the story.

This discussion signals several knowledge gaps in terms of the impacts of tillage practices on soil organic matter and soil carbon accumulation claims. Once again, these benefits will only accrue where crop residues are consistently retained for some period, normally after five years. The big question remains: should resource poor smallholder farmers be encouraged to eliminate tillage for the sake of long-term benefits that depend on crop residue retention? Are there suitable alternatives that may be adapted to farmers needs in SSA region?

2.4.4 Crop yields, food security and smallholder livelihoods

It is widely acknowledged that increased crop yields under no-till are only observed in semi-arid areas under conditions where moisture is the only limiting factor to crop productivity (Corbeels et al., 2014; Steward et al., 2018). In high rainfall areas, it has been reported that no significant differences in terms of crop yields between CA and conventional tillage systems have been observed and sometimes reduced yields have been reported in CA fields as reported in the literature (Giller et al., 2009; Ngwira et al., 2014). Correspondingly, crop yields are significantly lower in areas where nutrient deficiency is involved with little investment in inorganic fertilizers (Rockstróm & Barron, 2007; Vanlauwe et al., 2014). With lack of resources for increased inputs in the case of smallholder farmers (Giller et al., 2009; Njoloma et al., 2016), farmers stand the risk of having poor yields and food insecurity, thus making CA unattractive to smallholder farmers (Vogel, 1993a; Giller et al., 2009; Wall; 2010; Corbeels et al., 2014; Ngwira et al., 2014; Steward et al., 2018). Reported crop yield increases have been confined to smallholder farmers who participated in CA promotion projects through which they are provided with material incentives such as inorganic fertilizer, hybrid seeds and herbicides (Giller et al., 2009; Anderson & Giller, 2012; Andersson & D'Souza, 2014; Mazvimavi, 2016).

In a review of over 610 studies, Pittelkow et al. (2015a) give compelling evidence of no-till's ineffectiveness in terms of crop yields. According to Pittelkow et al. (2015a), no-till with limited mulching results in a 10% yield decrease, yield penalties smallholder farmers must bear. A recent study to assess the resilience of CA to climate stress such as droughts in Malawi (Steward et al., 2018) provides a divergent view of the story. By using rainout shadows to simulate conditions of in-season droughts and heat stress in the experimental plots, Steward et al. (2018) found that CA outperformed conventional tillage system in terms of crop yields. Such benefits do have limits too as suggested by many other authors such as Giller et al. (2009) and Andersson and D'Souza (2014). Beyond a certain number of rainout days or droughts, CA was found ineffective in providing the same benefits (Steward et al., 2018) which support similar findings by Jones (2000) and Pala et al. (2000) who observed that CA did not support crop growth under prolonged droughts in the Middle East. Elsewhere in Australia, Kirkegaard and Hunt (2010) and Kirkegaard et al. (2014a) found little evidence to ascertain yield increases in CA and specifically due to lack of soil tillage or no-till.

Where CA showed yield increases, many have observed that such increases do not come by because of improved soil health, but because of other factors such as application of inorganic fertilisers and herbicides (Lundy et al., 2015). Other factors contributing to yield increases are timely planting in many no-till systems and early crop establishment or where CA allows for growing of additional crops in the same growing season (Bolliger et al., 2006; Giller et al., 2009; Kirkegaard et al., 2014b; Giller et al., 2015;). Due to early planting, crops are established on time and take advantage of available moisture in the soils before droughts strike enabled because of elimination of tillage and where mulching reduces heat stress under the soil surface, reduces runoff and improves water infiltration (Giller et al., 2015; p. 5).

Despite others playing down the significance of these short and long-term crop yield gaps (Baudron et al., 2015), lack of short-term yield gains is a major factor contributing CA dis-adoption and poor uptake among resource poor farmers (Giller et al., 2009; Giller et al., 2015; Chinseu et al., 2019). For Malawian rural farmers, these yield gaps contribute to food insecurity and entrenched poverty that may be difficult to break away from. While most CA proponents continue to promote CA based on controlled experiments and experiences of rich commercial farmers in Americas, smallholder farmers learn about the challenges of practising these CA methods on their own to inform their next steps. Some 11 years on from Giller et al.'s critic of CA, CA promotion and research continue to be prescriptive and top-down. Once again, CA needs adaptation and further development to strike a balance between farmers' short term food security needs and long-term environmental benefits.

2.4.5 Local institutions, social capital, and farmer empowerment in CA

Despite the attention given to CA's contribution to the food security of smallholder farmers in SSA, there has seldom been much consideration of the social element such as farmer participation, the influence of existing local knowledge, social networks and local institutions. The most common occurring theme in CA literature for close to three decades has been the thinking that local people degrade their natural resources (land or soils) because local people's production technologies, culture and knowledge (also called

Indigenous Knowledge, IK) are limited in scope as well as primitive and destructive (Hobbs, 2007; Baudron et al., 2007; Thierfelder et al., 2013a; Ngwira et al., 2014; Njoloma et al., 2016; Mloza-Banda et al., 2016). This line of thinking has fostered demand for CA amongst development practitioners, governments and research institutes and has pushed away the relevance of farmers' local knowledge, institutions, and their innovativeness. The promotion of CA, apart from claiming to enhance resilience of farming systems, has been to transform and replace farmers' environmental and agricultural knowledge and practices.

Better understanding of smallholder farmers' livelihoods and situations emerged during 1970s through the convergence of applied anthropology and eco-agriculture where the latter formed basis for the emergence of the concept of CA (Howes & Chambers, 1979; Brokensha et al., 1980; Chambers, 1983; Chambers, 1989; Milestad & Darnhofer, 2003). In time, this evolved into a more holistic approach of thinking about smallholder farming, taking into consideration that despite having similarities, individual farmers are fundamentally different due to their unique social-ecological situations. One such as example is the influential Sustainable Livelihoods Framework (Figure 2.1) which incorporates the concept of livelihoods assets (Scoones, 1998; DFID, 1999; 2000). According to Pretty and Ward (2001), and Dixon et al. (2013), local knowledge and social capital are embedded and sustained in communities through people's relationships of trust and reciprocity, collective or common rules and action, belief systems and values and people's connectedness through multidimensional social networks. Indigenous knowledge and social capital are critical building blocks of local resilience and sustainability, and they influence farmers' adaptive learning, knowledge generation and testing through their own experiments. These are mirrored in agricultural practice where farmers are consistently involved in the process of experimentation and adaptation (Folke et al., 2002; Adger, 2003; Pelling & High, 2005).

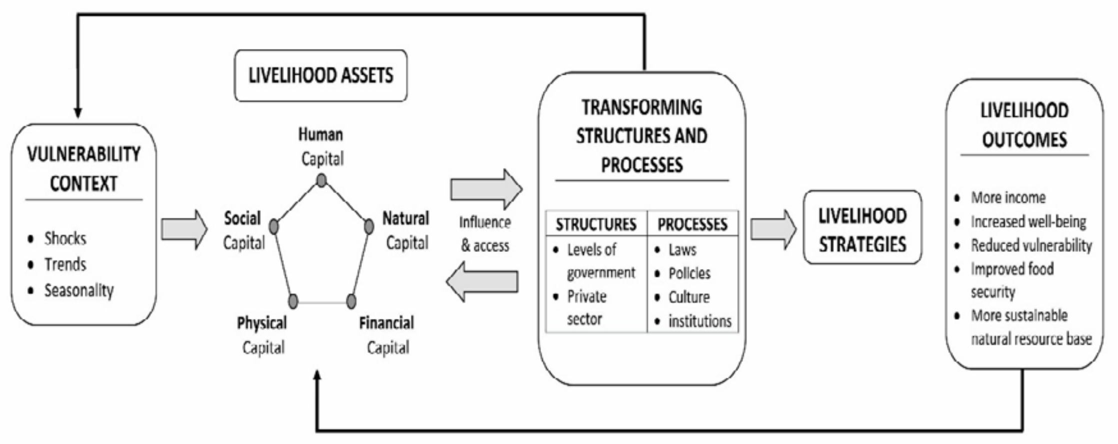


Figure 2.1 The Sustainable Livelihoods Framework (adapted from DFID, 2000)

Social capital has been defined as "*…social resources upon which people draw in pursuit of their livelihood objectives*" (DFID, 2001, p. 21). These networks are important aspects of analysis of sustainability. Farmers' access to social capital endowments provides platforms for them to work together, exchange information about what is new, deliberate on existing challenges and to develop leadership abilities and efficient organisation of development activities and resource management within the society. Indeed, social capital may provide safety nets among poor households and influence household livelihood decisions in pursuit of their livelihood objectives (Scoones, 1998; DFID, 2001). Accumulation and improvement of social capital amongst farmers may facilitate farmer innovation, sharing of knowledge and contribute to the improvement of other livelihood assets (see Chapter 3).

Despite consensus on the importance of local institutions and social networks in farmers' livelihoods (Spielman et al., 2011; Maertons & Barret, 2012; Hermans et al., 2013; Rendon et al., 2015), their consideration within CA remains scarce, with the possible exception of social networks being used to understand technology diffusion in order to improve CA adoption rates (Pretty & Smith, 2004; Achora et al., 2016).

For example, Monsalvo-Velazquez et al. (2014) undertook a social networks analysis of farmers in Mexico to understand connectedness in innovation diffusion. Their findings provide support for the importance of social networks for farmers and the diffusion of complex technologies as coined by Rogers (1995). Achora et al. (2016) focused on role of centrality and power positions in social networks for the acceptance or rejection of CA in Kenya by analysing social networks of various actors. Findings revealed that farmers depend on their fellow farmers for information about various agricultural technologies and to validate innovations' effectiveness before taking up any of the modern technologies. Their findings agree with Maertons & Barret (2012), Rendon et al. (2015) and Ramirez (2013 & 2015), suggesting the need to pay particular attention to the development and strengthening of farmers' social capital and their access to internal as well as external networks. Social capital and local institutions are especially vital in countries where agricultural extension services are crippled by understaffing and insufficient funding to the responsible government departments. For example, Ragasa (2017) found that resource poor smallholder farmers in Malawi depend on their colleagues to access, validate and evaluate new agricultural information to inform their adaptation and mitigation to emerging challenges.

Mutekwa and Kusangaya (2006) further demonstrated the impacts of participatory extension approaches that can lead to additional, but important benefits such as improvement of farmers' social capital (social networks). Farmers exposed to CA through participatory extension methods formed groups through which they were able to share their new knowledge and help each other with labour issues during peak times. Within the same thinking, farmer-to-farmer interactions have proven effective in training farmers in new farming methods (Hockett & Richardson, 2016). This suggests that social capital needs to be taken seriously if knowledge-extensive farming systems like CA are to be efficiently communicated to and amongst farmers (Khartaza et al., 2018). However, this important work does not consider the impacts of CA and its various forms of extension on farmers' social networks and accumulation of social capital. This knowledge gap requires attention from researchers to improve our understanding of CA extension approaches on farmers' social networks and local institutions and how such understanding can improve our extension approaches and help embed and adapt CA in farmers' own farming systems.

2.4.6 Farmer innovations through experimentation

According to Hoffmann et al. (2007), farmers are always involved in experimentation in various ways in order to cope with social-ecological changes and uncertainties that arise in their daily livelihood activities. While recognising the need to adapt current CA practices to make them more sustainable, literature on local adaptations and experiments remains non-existent. Both commercial and smallholder farmers always find themselves in need to adapt to and improve on their production systems and other livelihood activities in the face of change (Scoones, 2015; DFID, 2001). To continue providing essential ecosystem services of production and others, farmers must be able to build their own abilities to coping with ever-present challenges in the environment they operate in to maintain and enhance future abilities of their farm systems (Milestad & Darnhofer, 2003; Folke et al., 2002; Milestad et al., 2010).

According to Berkes et al. (2004) and Milestad et al. (2010), resilience is the ability or capacity of a system to buffer both spatial and temporal changes that occur in a social-ecological system. A resilient system is capable of absorbing system disturbances and reorganise itself in the face of change while retaining its essential functions, structure, identity and its feedback mechanisms that link it (Carpenter et al., 2001; Berkes et al., 2004; Walker et al., 2004; Milestad et al., 2010). In terms of smallholder farmers, their farming systems are resilient not only when they buffer changes in the environment such as climate changes, market fluctuations, or dwindling soil productivity at one point in time, but be able to do so at any point in future with new rising challenges of varying intensities. Here, the implication for smallholder farmers is that they need to be able to build resilience that is truly embedded in their farming systems to enable them cope with new rising challenges and to adapt and reshape their farming systems without losing their ability for future adaptation (Folke et al., 2002; Milestad and Darnhofer, 2003; Milestad et al., 2010). As Milestad et al. (2010; p. 770) put it:

> *"farmers have always lived in changing environments – socially, ecologically, economically, and politically – where surprise and disturbances are inevitable"*.

According to Gunderson & Holling (2002), and Berkes et al. (2004), major social-ecological changes can change system properties and relationships between humans and their environments and shift the system to a new equilibrium. As such, farming systems need to build resilience from within themselves and be able to adapt and assimilate such disturbances and maintain their productivity and usefulness (Fazey et al., 2007; Milestad et al., 2010). Bennet et al. (2005) and Berkes (2007) argued that resilience thinking provides an opportunity to consider challenges local people face in a wider view and through the lens of complex social-ecological systems like the SLF to better understand what makes them vulnerable to the ever-existing challenges. Using a number of case studies, Folke et al. (2002: pp. 9-12) identified four clusters of factors that would help in the analysis of the processes that facilitate building system resilience:

a) *Learning to live with change and uncertainty.*
b) *Nurturing diversity for system reorganisation and renewal.*
c) *Combining different knowledge types and sources for learning, and*
d) *Creating opportunities for self-organisation toward social-ecological sustainability.*

One important, but often neglected approach in helping build resilience and enhance sustainability of smallholder agricultural systems is farmers' on-farm experimentation, a phenomenon which finds its roots in the emergence of applied anthropology, specifically the 1970s and 1980s interest in cultural dimensions of rural agriculture (Chambers et al., 1983; Scoones, 1998). Scoones and Thompson (1994), Sumberg and Okali (1997), Hoffmann et al. (2007), Milestad et al. (2010) and others have described farmer experimentation as an important way farmers use their local knowledge, concerns and previous experiences to develop their new or adapted farming technologies. According to Rhoades and Bebbington (1995), farmers of all categories employ experimentation in one way or the other to attempt and learn to take charge of their environment and to keep their farms productive and profitable while going through changes. This study adopts the Quiroz's (1999) definition of farmer experimentation to mean activities where farmers introduce something new to their farming system or adapt existing components of their common practices in new ways with aims of either evaluating the effectiveness of that component of the system or to effect a desired change in their livelihoods.

A) Learning to live with change and uncertainty

Building farm and community level resilience requires that individuals learn to live with and adapt to change and emerging disturbances through continued knowledge acquisition and creation (Folke et al., 2002; Milestad et al., 2010). According to Hoffmann et al. (2007), on-farm experimentation also helps farmers spread risks and reduce impacts of a crisis. The lack of explicit support for farmers' innovations that would allow them learn and adapt in top-down CA approaches hinders this key aspect of adaptation. Linking this to SES as an approach that incorporates complexity for learning, the simplistic top-down approaches in CA fail to incorporate this adaptive learning from preliminary stages of promotion such that farmers learn of CA's complexity by themselves after funded programmes phase out. It is not surprising therefore that farmers tend to abandon CA practices soon after they are left to practise the technology on their own (Chinseu et al., 2019).

B) Resilience through nurturing diversity for reorganisation and renewal

Besides spreading risks, farmers experiment to diversify farm income and types of crops and varieties (Bentley, 2006). These types of experiments help farmers build biodiversity and resilience at farm and community levels (Folke et al., 2003; Milestad et al., 2010). Consequently, farm diversity provides pathways for adaptation and enhances resilience and sustainability of the farm system and wider social-ecological systems (Carpenter et al., 2001; Berkes et al., 2004). Diversity is also applicable in terms of the social system through which farmers' experimental knowledge becomes part of community or collective memory from which the community benefit in coping with future crises and to help them reorganise their farm systems after a significant crisis (Folke et al., 2002; Berkes et al., 2004; Berkes, 2007; Milestad et al., 2010). Farmers with a diverse network of actors (diverse social networks) stand better chances to cope with challenges in their localities (Reij & Waters-Bayer, 2001; Folke et al., 2003). Experimenting farmers enrich their networks with new knowledge and thus contribute to building community resilience to emerging challenges.

C) Resilience through combining different types of knowledge

Bentley (2006) argued that farmers combine diverse types and sources of knowledge in performing their experiments such as local knowledge developed through doing over a long period of time and scientific knowledge from extension agents and research institutes that work with farmers or from the media (Stolzenbach, 1999; Bentley, 2006; Sturdy et al., 2008). Because no single form of knowledge system is ever good enough for building resilience and agricultural sustainability (Alcon et al., 2003), farmers' use of combined approaches in their experimentation is an important aspect and a valuable tool to building local resilience at farm and community level. Through experimentation using such mixed approaches, farmers engage in knowledge generation, refining of ideas and enhancing agricultural resilience by adapting and modifying agricultural technologies (van Veldhuizen et al., 1997). What is unique about farmer experiments is the generation of knowledge that is site-specific and appropriate and suitable to farmers' own needs and aspirations. Better understanding of how such learning and knowledge generation influences farmers' agricultural practices, and their livelihoods is an important work that requires attention from the development community, governments, and agricultural extension agents.

D) Creating opportunities for self-organisation toward sustainability

One important feature of a resilient farm system is the ability to self-organise, used herein to mean the ability of the farmers to capitalise on opportunities in crises and being able to maintain control over their farming activities and profitability through challenging periods (Milestad et al., 2010). Experimentation provides opportunities for farmers to open to innovative ideas on how to turn around their farming systems while also helping themselves eliminate dependence on external help (Quiroz, 1999; Milestad et al., 2010). As Milestad and Darnhofer (2003) put it, creative solutions emerge where farmer experimentation allows the emergence of self-organisation to deal with change. It is important, however, to recognise the need to balance farmers' knowledge and experimentation and scientific knowledge in agricultural technology development in pursuit of building resilience and sustainability. As Milestad et al. (2010; p.778)

> "*systems that do not allow change will generate surprise and crisis. Systems that allow too much change and novelty will suffer loss of memory*".

With a strict view of what CA is or must be, little, if any, is known about the role and impacts of farmer experimentation in CA systems and how that influence resilience and sustainability of the farm and farmers' livelihoods. Before farmers can fully adopt or abandon any technology, the first step they do is try it out on a small piece of land to gain more knowledge about it (Schultz, 1975; Hockett & Richardson, 2016). One of the key reasons why CA has not been so successful in the SSA and Malawi may be related to the poor understanding of farmers' ability to experiment, evaluate, adapt and reinvent agricultural technologies. Where CA does not resonate with farmers' aspirations and social memory, poor adoption and dis-adoption of CA is expected. Unless the role of local knowledge and farmers' own experimentation is known, efforts of the CA proponents and the donor community and governments that promote CA to farmers are unlikely to see improvements in adoption.

2.5 Summary of knowledge gaps

This chapter has reviewed relevant CA literature, beginning with its development in Americas, its introduction in SSA as well as evidence for its effectiveness, suitability, and future adaptation prospects. Despite its origins in the more nuanced eco and sustainable agriculture traditions of the 1970s and 1980s, and a wider conceptual shift in rural development circles towards a more holistic understanding of farmers and their livelihoods throughout the 1980s and 1990s, the top-down prescriptive technology transfer approach to CA in SSA has made it difficult to streamline site-specific adaptation to help farmers build resilient and sustainable agricultural systems. Because CA has been promoted based on experiences from elsewhere, there exist significant gaps in knowledge about its site-specific effectiveness in offering multiple social-ecological benefits. The next chapter espouses these ideas forward and explains how adopting a SESs approach can help improve our understanding of the social-ecological impacts of CA and the technology’s sustainability.

Chapter 3

Researching the social-ecological sustainability of the DBF

Chapter Overview

This chapter discusses the philosophical underpinnings of the research design, data collection techniques, and analysis. The chapter combines the Sustainable Livelihoods Framework (SLF) and the Adaptive Cycle to devise a social-ecological model that forms a framework that guides and structures this research from data collection, analysis, and interpretation. The 'ecological' aspect of this research used on-farm monitoring, incorporating farmers as active participants while the social aspect used a number of qualitative data collection methods, which are also described in detail. The last section in this chapter relates to challenges faced during data collection and how they were managed to minimise negative impacts on the data collection exercise.

3.1 Methodology and research design

3.1.1 Post-Positivism

The analysis of DBF impacts on soil quality, soil erosion, and maize yields, is rooted in post-positivist thinking, which according to Bogdan and Biklen (2003) stems from positivism, a paradigm characterised by a set of strict scientific approaches to knowledge and facts as conceptualised by Auguste Compte (Chilisa & Kawulich, 2012). While positivism considers scientific procedures as being absolute truth and the scientist as being simply the one who observes and notes that truth, Niels Bohr (Crotty, 1998) diverged from this thinking to further state that truth is not an absolute certainty. Here, the scientist is not just an independent observer of reality, but is the one responsible for constructing meaning, thus reality is not an absolute truth, but is considered a probability to some level where there is not enough evidence to reject that that reality does not exist (Crotty, 1998).

According to Guba (1990), post-positivism is pluralistic and multiplistic in nature, and thus opens doors for researchers to use various quantitative and qualitative methods to triangulate findings through exhaustive study of the phenomenon from as many different perspectives as possible. The ontological argument of post-positivism is that a tangible reality does exist across space and time. According to Eichelberger (1989) and Creswell and Creswell (2018), the epistemological argument is that objectivity in research cannot be absolute, but better research methods can push findings closer to the true reality. As stated by Guba and Lincoln (1994), Ponterotto (2005) and Chilisa and Kawulich (2012), post-positivism is very influential in application, especially where a piece of research intends to falsify/verify causal relationship among dependent and independent variables. Particularly, this paradigm is important for the analysis of soil quality status on farmers' fields after conversion from CR to DBF. It provides opportunities to triangulate quasi-scientific experiment in soil and water analysis with qualitative data from farmers' lived experiences.

3.1.2 Constructivism/Interpretivism

Constructivism and interpretivism can be traced back to early studies of Edmund Husserl and his phenomenology philosophy that dealt with human consciousness and awareness and related concepts by Wilhem Dilthey (his theory of hermeneutics) and Martin Heidegger and Max Weber later on (Eichelberger, 1989; Neuman, 1997; Chilisa & Kawulich, 2012). Constructivism differs significantly from either positivism or post-postivism in its ontological, epistemological and axiological philosophy. Unlike post-positivists/positivists, constructivists/interpretivists believe that reality is socially constructed and that there are multiple realities, many of which are intangible ones just as there are many people who construct them (Creswell, 2003; Mertens, 2009; Creswell & Creswell, 2018; Creswell & Poth, 2018). Within this paradigm, reality is specific to a certain context, time, place, individuals or group of people sharing similar views about an object in a specific situation or historical context and therefore cannot be generalised (Creswell, 2003; Denzin & Lincoln, 2011; Chilisa & Kawulich, 2012). As opposed to positivism, constructivism/interpretivism recognises that research is value-bound (Denzin & Lincoln, 2011; Chilisa & Kawulich, 2012; Creswell & Poth, 2018). According to Creswell (2003) and Denzin and Lincoln (2005), this paradigm advocates for phenomenological approaches to research where research takes place in people's own natural environments to explore and understand their lived experiences and what counts as knowledge in their own contexts.

Constructivism and phenomenology have profound importance in this study for a number of reasons. First, previous studies about CA benefits appear to have paid little attention to farmers' own diverse social-ecological scenarios. As a result of over-reliance on positivism, knowledge gaps exist on what works and what does not for various categories of farmers and in various locations. This knowledge gap restricts site-specific CA adaptation, impacting negatively on the sustainability of these farming systems. Secondly, the impacts of CA projects on farmers' institutions and social perspectives have been poorly understood since most scientists are focused on finding evidence that CA works, whether that is on research stations or on donor-funded farmers' plots. Gaps in terms of what works and what does not between farmers and researchers, donors, governments and NGOs still exist. By incorporating constructivism, this research attempts to bridge this gap in knowledge while focusing on site-specific sustainability of the DBF in Malawi.

3.1.3 Researcher's positionality and ethical considerations

Coming from northern Malawi, the researcher has some similarities with participants' cultural beliefs and experiences growing up in similar socioeconomic conditions. The researcher spent two years (2015-2017) living within 2km from one of the study sites while working on a research project in collaboration with Tiyeni, whose DBF system was one of the incorporated interventions. Such exposure to research participants and DBF promoter inevitably shapes subsequent relations with them. Having grown up in similar subsistence farming family myself, discussions around DBF's impacts on household food security could likely be skewed towards farmers' narratives. For objectivity in this research, these experiences and beliefs had to be ignored. The preliminary study (Section 3.3.3) allowed the researcher to become immersed with the study participants and Tiyeni, relating these to the literature and paradigms discussed above, making it possible to evaluate previous assumptions and beliefs.

It is important to recognise that working with women in the context of rural Malawian cultures brings its own ethical issues. For example, women are supposed to be submissive among men. Working with a group of both men and women required an acknowledgement of this because it helped to ensure that women presented their voices irrespective of the presence of their male counterparts. Having grown up in similar cultural backgrounds, some women may have felt the need to be less confrontational during group activities and face-to-face interviews given the presence of male group members and researcher's gender, respectively. On a positive note, knowing that this was the case helped ensure that a conducive environment to let women freely express their views was created. Furthermore, having worked with similar groups of farmers on a post-doctoral research project ensured that appropriate interventions were taken when working with female farmers. One such approaches was to make sure that individual farmer interviews were held in environments of a farmer's choice.

This research involved working with groups of farmers who were trained by Tiyeni to practise the DBF in northern Malawi. As per University of Worcester's research ethics guidelines, an ethical application was made to the Humanities, Arts and Social Sciences Research Ethics Committee (HASSREC) which was approved on 29th May 2018 (see Appendix 2). Participation in this research was entirely voluntary. Participants provided their consent by way of signing a consent form, indicating whether they wished their names anonymised or not. While farmers provided consent for their real names to appear in the thesis, initials and prefixes have been used to protect participants' identities. It should be noted that photographs of farmers appearing in later chapters were used with the farmers' consent. Captions of such photographs have pseudonyms instead of actual names of the farmers. Lastly, participants who felt that they no longer needed to participate in the research were free to stop doing so at any point of the project stage. To manage expectations that often come with both research and development projects such as receipt of handouts, the consent form (Appendix 1) was specifically designed to give farmers enough information about the main aims and objectives of the research and advantages and disadvantages for choosing to participate.

3.2. Theoretical and analytical frameworks

Traditionally, social and ecological scientists have carried out their studies using their disciplinary approaches, limiting holistic understanding of the interactions between social and ecological systems (Ostrom, 2007; 2009; Gallopin, 2006). However, recent debates have focused on the argument that disciplinary research approaches are simplistic in nature and do not provide better understanding of the interactions between the social and ecological systems, also called social-ecological systems (SESs) (Ostrom, 2005; 2007). A new paradigm known as systems thinking, a parent of SES, arose under the premise that the seemingly separate human system is an intrinsic part of the ecological system embedded and intertwined through interactions and feedback mechanisms (Walker et al., 2004; Ostrom, 2005; Gallopin, 2006; Ostrom, 2007). Given such interconnectedness and inseparability of SESs and the variability across time and space, interdisciplinary research approaches are better suited in the analysis of impacts of interventions that cut across social and ecological boundaries.

The DBF presents similar challenges in that it is promoted and practised by farmers with various and complex social-ecological systems. Understanding of site-specific interactions because of the implementation of DBF in various communities is key to understanding DBF and CA sustainability and extent of their impacts at large. Despite its prominence as a crucial approach to research and managing the natural environment, the Social-Ecological Systems Framework (SESF) (Ostrom, 2009; McGinnis & Ostrom, 2014) has not been widely used in agricultural studies. One reason for this is that the framework was originally developed as a research and management tool in the filed of natural resources management, thus it places more weight on describing what should be monitored rather than its wider application (Ostrom, 2005; McGinnis & Ostrom, 2014). Consequently, field operationalisation of the original SESs framework in agricultural studies becomes problematic thus requiring adaptation (Binder et al., 2013). One example that incorporates SESs concepts which has also been widely used in research like this one is the Sustainable Livelihoods Framework (SLF).

3.2.1 The Sustainable Livelihoods Framework

The promotion of new farming methods like DBF in developing countries is aimed at increasing resilience of farmers to SESs dynamics and contribute to improved food production, improved livelihoods and enhanced ecosystems on which farming depends. The analysis of a farming system's sustainability needs to take into consideration both social aspects and the ecological parameters that together increase resilience of the farmers to the changing SESs. Among many SES approaches, the Sustainable Livelihoods Framework (SLF) takes a holistic approach into the analysis of different components of the sustainable livelihoods (Chambers & Conway, 1992; DFID, 1999) by recognising different assets people need to combine to yield the desired livelihood outcomes (Figure 3.1).

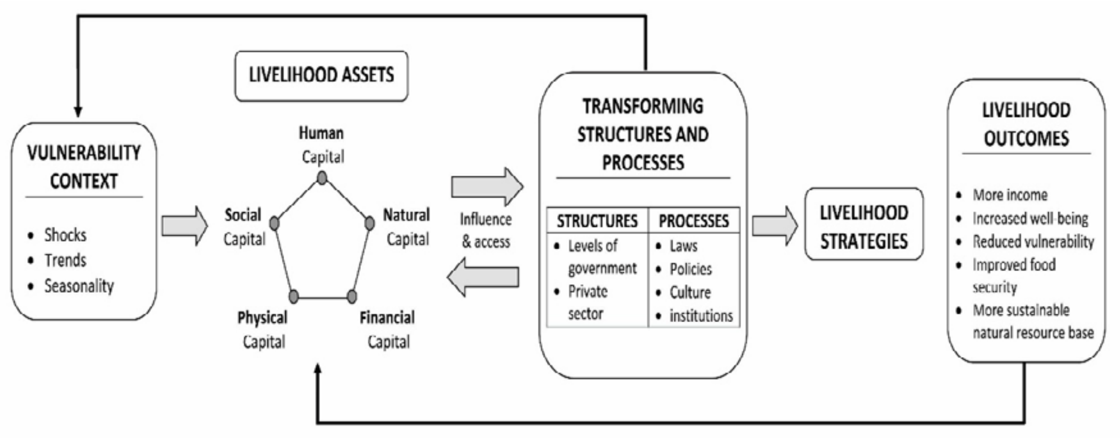


Figure 3.1 The sustainable Livelihoods Framework (adopted from DFID, 1999: 11)

The SLF is a valuable tool in the analysis of SES, recognising that each place is different from another, both in terms of social and ecological systems while also recognising the important interactions between them. The framework is anthropocentric in nature, making it a convenient approach to analysing the impacts of the DBF on people's livelihoods (Scoones, 2015). It recognises that individuals have differing resource endowments (livelihood assets) and circumstances that determine how they combine different resources (strategies) to achieve their aspirations (livelihood outcomes) and that these are subject to constant change at various temporal and spatial scales (Carney, 1999). The underlying argument being that a better understanding of the impacts of the DBF on farmers' livelihoods requires that one recognises that the same technology will have differing impacts on different individuals and communities. At the centre of the discussion in SLF is idea of achieving livelihood sustainability. Chambers & Conway (1992: p.6) defined sustainable livelihoods as:

> "*A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base*".

According to Nguthi (2007), livelihood capitals are described as the general stocks of assets or productive resources that are generated through human actions and can be consumed, depreciated, or utilised during the production process to achieve desired livelihood outcomes. In the literature, these different capitals have been portrayed in many ways. Chapman et al., (2003) illustrated the five forms of livelihood capitals as a great circulating wheel, depicting their ever-changing nature. Scoones (2015; 2005) compared these asset endowments as an economic base that works as a launch pad in achieving different livelihood outcomes.

Access to and ownership of these capitals are critical for sustainable livelihoods given that they influence and determine livelihood strategies any one farmer has at any point in time (Neihof & Price, 2001; Nkala, 2012). Development interventions must target increasing people's capitals that would widen their livelihood strategies for achieving all outcomes. In this study, farmers use DBF as a vehicle to enable them improve their ownership and access to assets to achieve desired livelihood outcomes and reduce their vulnerability. The SLF has been widely used for project impact evaluation, policy identification, review and formulation by various scientists and development organisations in SSA (DFID, 1999; Ashley & Carney, 1999; Nguthi, 2007; Nkala, 2012; Griffiths, 2015; UNDP, 2017). Chapter 6, therefore, adopts this framework to analyse and contextualise the impacts of the DBF on farmers' livelihoods while Chapter 7 uses the concept of social capital to analyse how Tiyeni's extension system impacts on local institutions and information flow as apparatus for nurturing local adaptation and resilience.

Given its anthropocentric nature, however, the SLF struggles to conceptualise the complexity of SESs and hence is arguably limited in application as a standalone framework to explain the aspects of DBF adaptation and sustainability. For example, the ecological aspect of the SESs is simplified and represented here as natural capital (Figure 3.1), underplaying the complexity of ecological systems themselves. Unlike Gunderson and Holling's (2002) adaptive cycle (see Section 3.2.3), which recognises the fact that sustainability is not simply the achievement of certain outcomes, sustainability in the context of the SLF entails achieving all the livelihood outcomes simultaneously (DFID, 1999). Despite its limitation, the framework remains a useful tool in reconciling two aspects of this research; DBF impacts on soil fertility and how other livelihood assets affect extent and sustainability of the changes in soil properties. To understand DBF adaptation and resilience, the SLF is used in combination with the Adaptive Cycle (Gunderson & Holling, 2002). The next sections turn to these concepts as they apply to this thesis.

3.2.2 Resilience and sustainability

It is important to understand that the definition of sustainable livelihoods raises two key points: coping and recovering from shocks and pressures. Coping with shocks and pressures is a key characteristic of a resilient system, defined as the ability of SESs to buffer change and maintain salient characteristics and features when subjected to perturbations or disturbances (Holling 1973). On the other hand, adapting to or recovering from severe shocks and pressures is another equally important characteristic of a resilient and sustainable system (Smit & Wandel, 2006; Berkes et al., 2004).

As Putnam (1995) and Berkes et al. (2004) put it, resilience is site-specific and dependent on people's asset endowments, transforming structures and processes and extent of shocks and pressures on a particular SES. Following this line of reasoning, sustainability then is not a one-time achievement. Rather, it is a continuous process of learning and adapting to new shocks and pressures as Figure 3.2 illustrates (Berkes et al., 2004; Folke, 2006). The implications of this are that findings at one point and location cannot be generalised into a larger DBF community. There is need, therefore, to understand what works and what does not and to highlight conditions under which the DBF is more suited.

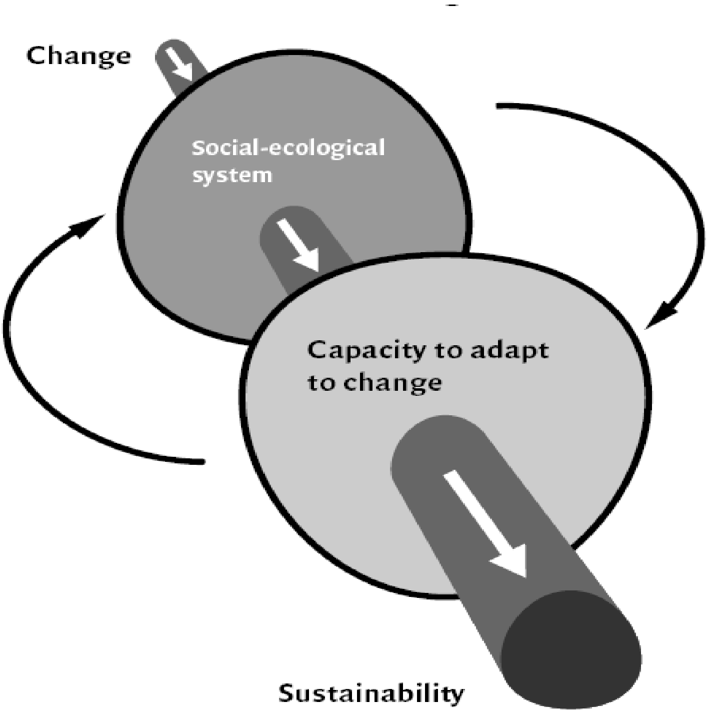


Figure 3.2 Visualising the concept of sustainability (from Berkes et al., 2004: p.4).

> "*…resilience is an important element of how societies adapt to externally imposed change, such as global environmental change. The adaptive capacity of all levels of society is constrained by the resilience of their institutions and the natural systems on which they depend*".
>
> Berkes et al. (2004, pp. 14)

The application of the concept of resilience has been widely adopted in many environmental studies, especially those that deal with SES concepts (Gunderson & Holling, 2002; Berkes et al., 2004; Griffiths, 2015). Except for Darnhofer (2009), Darnhofer et al. (2010), Sinclair et al. (2014) and few others, application of SES in agricultural studies remains uncommon. The importance of resilience and adaptation in building farm system sustainability cannot be overemphasised.

Resilience thinking allows scientists to consider a SES as going through change and not stability (Berkes et al., 2004; Folke, 2006). This point is particularly key in understanding the sustainability of CA and smallholder farmers' resilience to existing and future threats as they always operate in changing environments. As Griffiths (2015) posits, the concept of resilience requires consideration of farmers' social capital, their adaptive and coping capacity, vulnerability context and farmers' own perceptions of risks and opportunities in their environment and societies in which they operate for their livelihood. Chapters 7 and 8 apply these concepts in understanding the impacts of Tiyeni extension approach on farmers' social capital and local institutions and local adaptation, respectively.

3.2.3 The adaptive cycle

Amongst many models that describe SESs is the adaptive cycle (Gunderson & Holling, 2002; Folke et al., 2006; Walker et al., 2006). In discussing the ability of farm systems to adapt to change within the resilience thinking, it is important to discuss some key points of the adaptive cycle and to establish its importance in this investigative work. The adaptive capacity of smallholder farmers forms both theoretical framework that help structure investigations about local adaptations and provides useful approach in understanding feedback mechanisms within the DBF SESs.

According to Holling (2001), Allison and Hobbs (2004) and Darnhofer et al. (2010), the adaptive cycle (Figure 3.3) is a four-phased model designed to provide conceptual insights into the processes of change in complex systems where understanding system uncertainty through continuous exposure to perturbations is an emphasis. As initially coined by Gunderson and Holling (2002: p. 34), the adaptive cycle comprises growth phase, conservation, release and reorganisation phases that represent ecosystem functions and operating under certain degree of system components connectedness, level of resilience and potential internal and external perturbations (Gunderson & Holling, 2002; Allison & Hobbs, 2004; Griffiths, 2015). These also determine the rate of phase transition.

The growth phase (r in Figure 3.3) is the first phase of the adaptive cycle. Here, resources that are used for building system structure and resilience are plenty. However, as the system grows, more resources are needed to maintain the structure (Gunderson & Holling, 2002; Walker et al., 2006). Conservation (K) is the phase where the net system growth slows down, becoming more complicated while less flexible, thus becoming more vulnerable to perturbations (Gunderson & Holling, 2002). According to Walker et al. (2006), the transition from growth to conservation phase is termed the Fore Loop. It is this transition that leads to development in society (Walker et al., 2006). Release (Ω) is the phase where a system, complicated, less flexible, and more vulnerable, is exposed to perturbations and crumbles down (Gunderson & Holling, 2002). Here, the system loses its structure. Finally, after collapsing, a system is now ready for novelty, where a new form of system dynamics develops. A new growth phase begins through reorganisation (α).

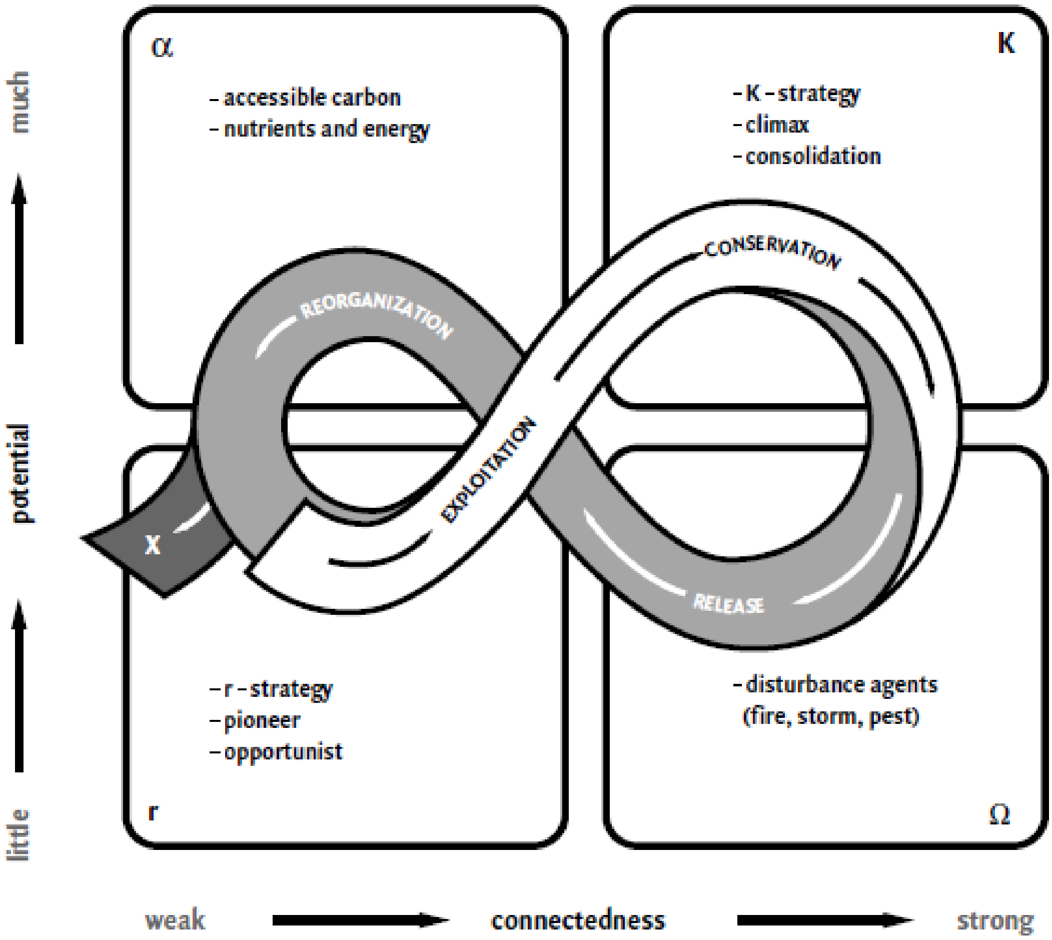


Figure 3.3 The Adaptive Cycle (Berkes et al., 2004, p. 17)

In the case where a system transitions from α to Ω, this process is termed the 'back loop' in which a new status quo emerges. Walker et al. (2006) and Griffiths (2015) call this 'bouncing forward'. Here, the system does not return to the previous state due to prevalence of factors that shift system's dynamics to a new equilibrium. It must be noted, however, that a system can bounce back to its previous state, provided conditions for such a process are met. Of particular interest in this thesis is the reorganisation phase, especially in terms of agricultural systems and farmers' livelihoods when hit by shocks and pressures that expose farmers to risks. Farmers' capacity for reorganisation to these forms the adaptation of their farm system, repositioning themselves to be able to buffer future challenges. Many agricultural and rural development interventions must be made to help farmers reorganise themselves and build their own resilience through various pathways that will further be discussed from Chapter 6 onwards. One importance of understanding feedbacks between the social system and their interactions with the natural system is that it provides better understanding of how farmers themselves respond to social-ecological changes in their lives. As discussed in the methods section, traditional research methods have neglected these types of interactions. The adaptive cycle helps visualise these complex processes and provide opportunities for understanding impacts of various interventions on adaptation to challenges.

3.2.4 SES model for investigating Tiyeni DBF farming system

As Darnhofer et al. (2010) and Sinclair et al. (2014) postulate, application of a SES approach in agriculture is still in its infancy level. Despite not being common in CA, these concepts have been applied in policy and decision making in dairy farming in Australia (Sinclair et al., 2014). While not focusing on any specific farming activities, Darnhofer et al. (2010) also showed the usefulness of adaptive capacity in sustainability analysis through their review of research papers on adaptation. The actual application of these concepts in agriculture studies is not well developed, thus they require complimentary frameworks to be fully useful at this stage.

This work, therefore, integrates the SLF and the adaptive cycle concepts into one SESs model to organise, link and interpret the proceeding chapters (Figure 3.4) and to provide a coherent structural basis on which the overall thesis is built. Specifically, the SLF is applied to livelihoods analysis in Chapter 7 and local institutions and social capital in Chapter 8 while also relating farmers' lived experiences to triangulate findings in Chapter 6 (Feedback loops in Figure 3.4). The adaptive cycle is specifically used in Chapter 8 to understand resilience through farmer experiments while also linking this to the influence of social networks on information flow and feedback mechanisms in Chapter 7. The combination of these takes root in Chapter 9 which answers the overall social-ecological sustainability question of the DBF.

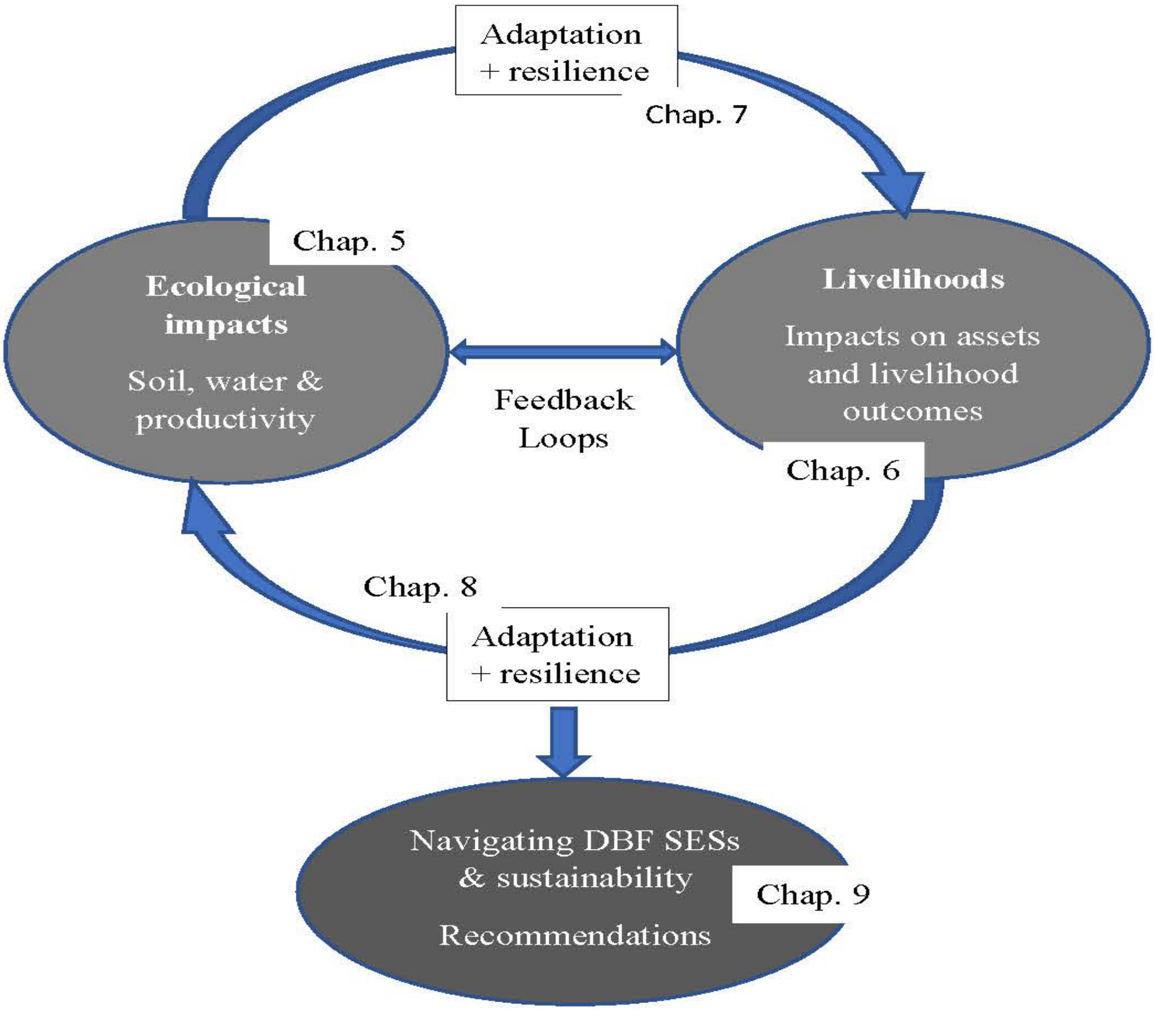


Figure 3.4 Model for investigating the social-ecological sustainability of the DBF.

3.3 Methods

3.3.1 The study design

This research takes on Convergent Mixed Methods research design, a type of mixed methods research originating in the social sciences and education disciplines from the writings of Campbell and Fisk in 1959 (Creswell & Creswell, 2018). These owe their existence to the belief that no single research method is truly free from biases and weaknesses (post-positivism and constructivism) and that use of multiple research methods helps to offset these biases and weaknesses so that the interpretations and conclusions drawn from the results closely reflect reality of the phenomenon under investigation (Tashakkori & Teddlie, 2010; Denzin & Lincoln, 2018; Creswell & Poth, 2018,). The 1990s saw mixed methods research becoming a distinct research methodology (Tashakkori & Teddlie, 2010) where such a field provided basis for viewing this approach as a way of converging quantitative and qualitative methods in research (Jick, 1979; Creswell & Plano Clark, 2018). Creswell and Creswell (2018: p.14) defines convergent mixed methods research as "*involving the combination or integration of qualitative and quantitative data in a study*". The first characteristic of this research design is the collection of both qualitative and quantitative data to answer research questions and their integration in the discussion sections of the chapters (triangulation) as Figure 3.5 shows.

A few assumptions must hold true for choosing the mixed methods research design. Firstly, it is assumed that both quantitative and qualitative data collection approaches provide different forms of data used to answer research questions (Creswell & Creswell, 2018 p. 213). Secondly, it is assumed that each of the data collection techniques has its own strengths and weaknesses and hence their combination helps reduce their individual weaknesses through triangulation. Lastly, this research design works where qualitative and quantitative data is collected on the same variables which provides a platform for comparison in the discussion sections.

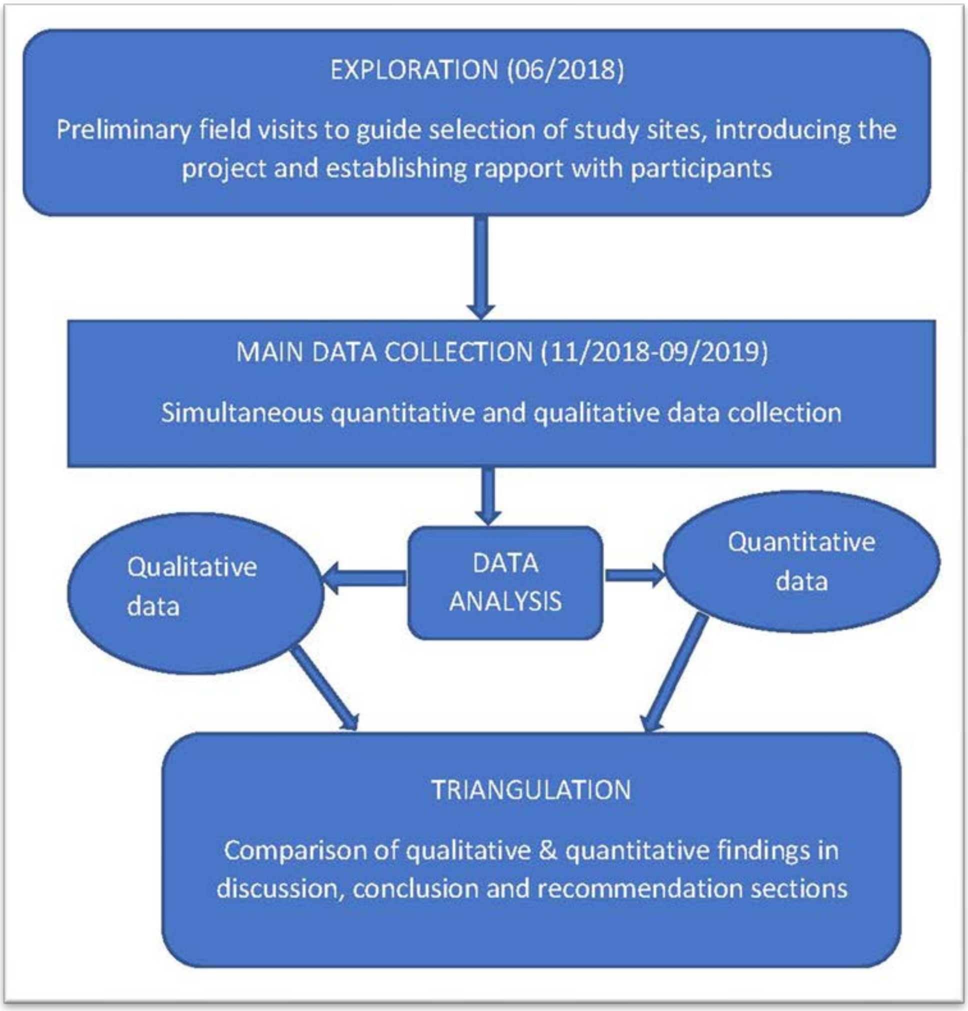


Figure 3.5 The convergent mixed methods design conceptual framework.

3.3.2 Sites selection: Space-for-Time substitution and phenomenology

As CA literature suggests, CA impacts, especially on soils tend to manifest after some time of implementation, most from two years and five years of CA use (Giller et al., 2009; Corbeels et al., 2014a; Thierfelder et al., 2018). To capture changes in soil ecosystem and farmers' livelihoods across time, study sites selection was based on an ecological concept known as Space-For-Time (SFT) substitution (Jenny, 1941 as cited by Pickett, 1989; Strayer et al., 1986). Due to the need for long-term experiments to capture spatial and temporal ecological dynamics, ecologists have often used a sampling methodology where sites are selected based on how long each one of them has been exposed to a phenomenon being studied (Picket, 1989). The major assumption of this approach is that social-ecological variations are equivalent across space and time, thus one can infer changes within the system across time by using sites/samples with varying exposure time to the phenomenon (Pickett, 1989: p. 110: Jenny, 1941 as cited by Picket, 1989). This technique was used due to its ability to track changes in a system across time by using different aged sites on farmers' own fields.

SFT in CA experiments has not been common, except for a few studies such as Mloza-Banda et al (2016) and Njoloma et al. (2016). One explanation for this literature paucity on SFT could be linked to CA studies' focus on on-station experiments to help provide evidence for its promotion. In a similar fashion to the work of Nkala (2012) and Njoloma et al. (2016), Mloza-Banda et al. (2016) compared impacts of no-till and CR on soil properties by use of paired plots from two- and five-year-old study sites in Malawi. With such successful application of this concept, this study uses this concept in its initial site selection stage to select communities which had used DBF for two and five years respectively.

Overall, qualitative sampling procedures targeted participants with lived experiences of DBF and Tiyeni (Creswell & Poth, 2018). Like SFT strategy, Maximum Variation (Creswell & Poth, 2018) was adopted to guide sampling strategy in the selection of study sites to maximise variations in DBF experiences across communities and among individuals. The major factors considered in this second level selection criteria included:

1. Variations in DBF experiences across temporal scale: two and five-year experiences.
2. Topographical differences; from undulating to steep slopes.
3. Rainfall; high to medium rainfall areas.
4. Major soil types; from areas with sandy soils, shallow/high silt-content to loamy and well drained soils.
5. Socio-economic differences among individual farmers were not actively used as a criterion here given that the study's central argument is that everyone is different.

Lastly, an opportunistic approach (Miles & Huberman, 1994; Hammersley & Atkinson, 1995) in selecting individual farmers for the study was used. This approach provided flexibility in the field to respond to changes such as participants who wanted to drop out of the study for personal reasons or because of decreasing enthusiasm in participating in the research activities. Initially, the study sought to include farmers who had abandoned the practice (DBF) to provide alternative perspectives. First fieldwork in the study area selection process proved difficult to include those who had already stopped using the technology given that most of them were not interested in spending time discussing something they already abandoned or because they had some personal issues with the groups' leadership or with Tiyeni where handouts were not provided as expected. Instead, their perspective was inquired from those who freely participated in the research. Figure 3.6 illustrates and summarises this qualitative sampling design.

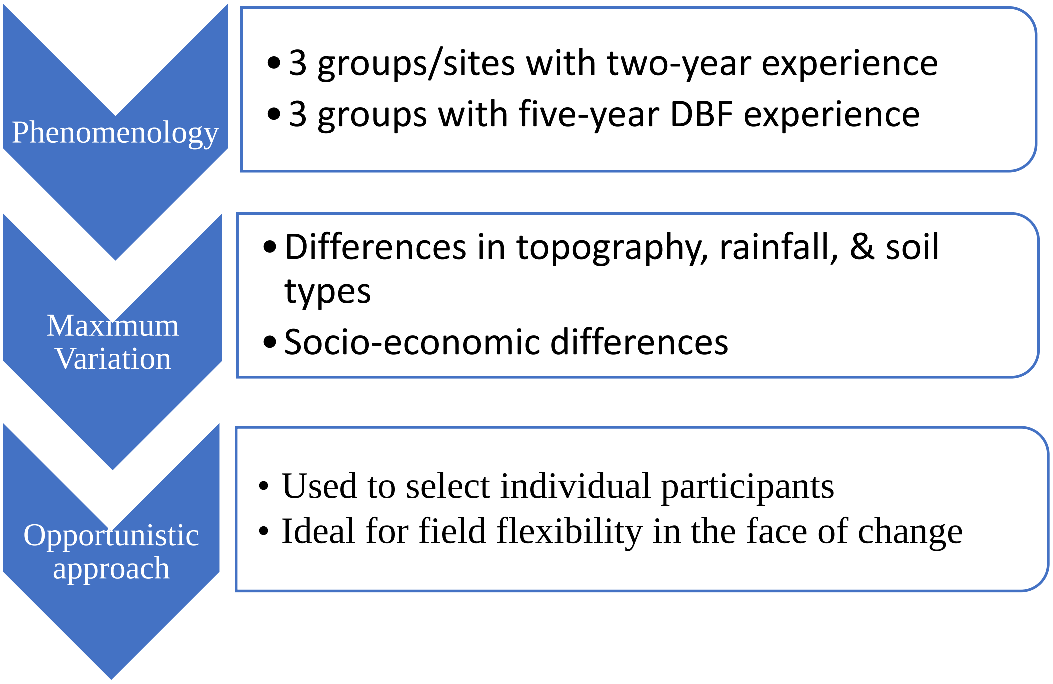


Figure 3.6 Illustrated sampling procedure.

3.3.3 Research participants

Given the complexity of mixed method research data needs (Creswell & Creswell, 2018), the number of participants for this study needed to strike a balance between quantitative and qualitative sampling requirements (Section 3.3.3). Due to time-demanding nature of qualitative data, Creswell and Creswell (2018) recommend a sample size of between 5 to 25 participants. Conversely, representative sample size in quantitative data required increasing sample size to at least 30 participants (Field, 2009), which would in turn double or triple time and financial resources in collecting qualitative information. Given this dilemma, it was decided to limit the number of plots for environmental monitoring to a total of 24 plots comprising 12 DBF 12 CR contiguous plots (Section 3.4.1) which still falls under allowable sample size (Creswell & Poth, 2018; Creswell & Creswell, 2018). However, group activities involved all group members in each community for a collective consensus.

Limiting the sample size to 24 plots in soil and water monitoring aspect (Chapter 4) may also have reduced statistical power of the analysis performed (Field, 2018). For example, comparing contiguous DBF and CR plots meant analysing results from only 12 plots. A similar situation arose when analysis required comparative analysis of between groups i.e., two-year DBF vs five-year DBF. Interpretation of results in this case included calculating statistical power for each group to reduce interpretation errors arising from this (Chapter 5).

3.4 Data collection

The first category of data collection exercises is dedicated to the ecological monitoring which involves on-farm soil quality status assessment, soil erosion and maize yield measurements (study 1 below). A total of eight techniques under Participatory Rural Appraisal (PRA) (sometimes termed Participatory Learning and Action (PLA)) formed the central data collection techniques for this research. These included group discussions, in-depth interviews, transect walks and mapping, timelines, and flow charts, illustrations and diagrams, Venn diagrams and proportional piling and ranking. Every farmer discussion was recorded using a digital voice recorder.

PRA developed and evolved as a reaction to traditional quantitative research methods characterised by surveys and questionnaires (Chambers, 1999; Dixon, 2000; Campbell, 2001; Cornwall, 2004), criticised for not being able to capture the complexity of rural people’s lives (Chambers, 1997). Secondly, Chambers (1983) argued that better understanding of rural people’s livelihoods are only well understood by the local people themselves, thus extractive research approaches do not capture site-specific SES knowledge and interactions (Chambers, 1983; Chambers, 1985). Another important criticism of the traditional research methods stems from what Chambers (1983; 1992) and Chambers and Conway (1992) refer to as ‘rural development tourism’, where researchers/development experts have biased visits to accessible parts of communities for quick answers to their questions. Since the 1980s, PRA methods have been widely used in the field, both in development and academic research projects across the world (Chambers, 1981; 1983; 1995; Pretty et al., 1995; Campbell, 2001; Griffiths, 2015; Cornwall, 2004; Creswell and Poth, 2018; Denzin & Lincoln, 2018;).

Much as traditional methods are characterised by quantitative data collection techniques, PRA does not necessarily exclude them. Rather, it advocates for the balance of both qualitative and quantitative methods that provide better understanding of a topic under investigation than where only qualitative or quantitative methods are used (Cornwall & Fleming, 1995; Dixon, 2000). This combination is an important aspect in both providing academic rigour, triangulation and reducing researcher biases (Scoones, 1995). PRA’s major advantage over other methods is the flexibility in operation and ability to combine different fields of studies that would otherwise not be able to be merged in traditional quantitative techniques alone (Dixon, 2000). This point is particularly important in the sense that this thesis goes beyond disciplinary boundaries, combining issues to do with agriculture, ecology, hydrology, economics, and sociology.

3.4.1 Study 1: Soil quality and maize yields

The first study aimed at analysing the environmental impacts of DBF and its sustainability by assessing: (1) its impacts on soil chemical and physical parameters, (2) quantifying soil loss as a result of soil erosion, (3) measuring maize yield differences between DBF and CR and (4) exploring farmers’ knowledge of soil and maize yield dynamics in the context of their DBF experiences. To answer these questions, on-farm and off-farm activities were conducted. First, twelve farmers, two from each group/community, volunteered to have paired DBF and ridge-based monitoring plots on their farms.

Amongst the volunteers, two farmers with both DBF and ridges on the same farm were then selected by the group members. Since these plots are on the same farm with the same historical background, it is assumed that the only difference in soil quality status would be because of the use of a different tillage system, the DBF. Four paired plots were then established in each community, totalling 24 plots for all six communities/groups, 12 DBF plots and 12 conventional ridge plots (Figure 3.7). Each plot was 4m by 10m ($40m^2$) located on farmers' larger DBF or CR large plots ranging from 0.0025acres and 5 acres respectively. The $40m^2$ paired monitoring plots were one metre apart located as Figure 3.8 shows.

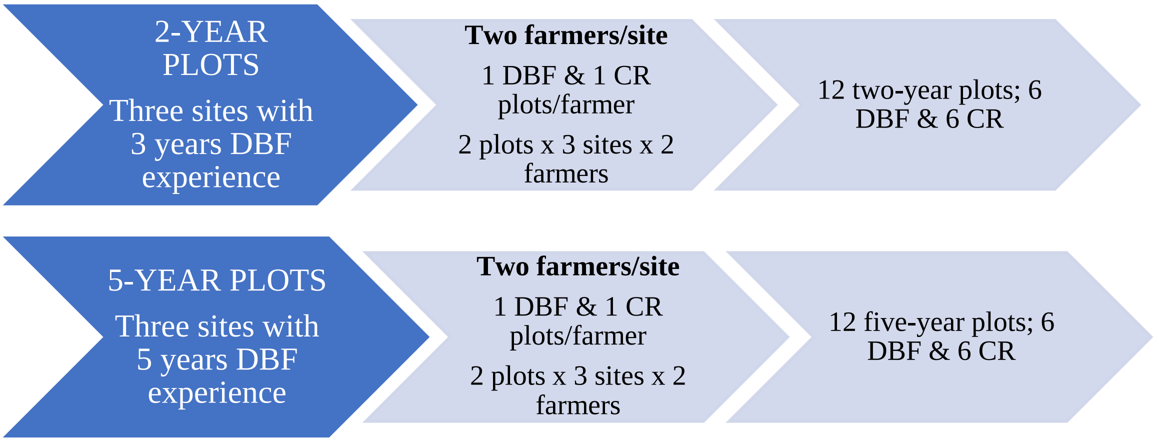


Figure 3.7 Distribution of 24 plots in 6 two- and five-year sites comprising 12 DBF and 12 CR

Plot setup followed soil erosion monitoring procedures by Benyamini (2004) and Bunning et al. (2011). Physical barriers and deposit collection troughs around the 24 plots were made (Figure 3.8). This technique encourages participation and learning on the part of the farmer since most of the activities can be done by the farmer, and it also provides direct measurements and quantification of soil loss through erosion unlike soil loss estimation models like Revised Universal Soil Loss Equation (RUSLE) and Soil Loss Estimation Model for Southern Africa (SLEMSA) (Hudson, 1981; Kilewe, 1985). A standard notebook was given to each farmer to record all farming activities undertaken in each plot such as crop varieties, planting and weeding dates, fertiliser and manure contents used, and maize yield measurements. Soil deposits were harvested from each plot every two months from November 2018 to April 2019. The harvested deposits were sun-dried and weighed on a spring balance with the help of farmers.

Figure 3.8 Soil erosion monitoring plots with troughs at Grace Phiri's farm.

Water infiltration tests to assess impacts of DBF on water infiltration rates were conducted on each plot using a 15mm diameter infiltration ring, a digital timer and 400ml calibrated container. Time taken for 400ml water to infiltrate into the soil was then recorded. The final reading was an average of three tests.

Soil sampling and laboratory analysis

Soil samples were collected in April 2019 with three laboratory technicians from Lunyangwa Research Station. Two composite soil samples were collected using an auger from 0-20cm depth (topsoil) and 20-40cm depth (sub-soil). For each depth (0-20cm and 20-40cm), 24 sperate composite samples were made. A total of 48 samples from 24 plots were collected. These 500 g composite samples were made by mixing and sieving five soil samples: one from the centre of the plot and four random points (Petersen, 1994; Chilimba et al., 2012). These samples were processed at Lunyangwa Research Station in

Mzuzu. They were analysed for pH, electrical conductivity (EC), organic matter content (OM), organic carbon (OC), nitrogen (N), available phosphorus (P), and bulk density (BK). The analysis of these parameters was based on standard procedures by Mehlich (1984), Anderson and Ingram (1993), Wendt (1996) and Chilimba et al. (2012).

Maize yield measurements: Each plot was harvested as a whole, and the cobs were shelled and dried as farmers normally do. Maize grains were measured using 20 litre buckets and on a spring balance and recorded in notebooks. The 20-litre bucket, which normally weighs 20kg when full, is a standard measurement equipment for farmers in Malawi hence its use. This lets farmers understand yield in their own terms apart from kilogrammes on the spring balance.

3.4.2 Study 2: Farmers’ livelihoods

The second objective focuses on impacts of the DBF on smallholder farmers’ livelihoods outcomes and sustainability. More specifically, this sought to assess impacts of DBF on household food security, labour shifts, and income. This would then help understand deep beds’ contributions towards farmers’ adaptive capacity and resilience to both social and ecological changes in their various communities. The aim was to gain a detailed understanding of farmers’ lived experiences by employing several participatory data collection techniques. Group discussions, proportional piling and ranking, timelines, flow charts and seasonal calendars were used during group meetings for data collection. This study also focused on the twelve individual farmers as case studies to further learn variations that exist from farmer to farmer and from community to community. For individual farmers, this study’s main data collection method was the face-to-face in-depth interviews.

Group Discussions

These discussions involved all members of each of the six groups in an open environment where the researcher played the role of a facilitator, with guiding topics for each discussion. Attendance of the farmers was varied from one group to another and from one activity to the other, depending on either the number of members in that group or the availability of the farmers on each occasion. Table 3.2 provides a summary of how many activities were done.

Each of these discussions focused on one study theme at a time. The theme for each group discussion followed broad questions about soils, livelihoods, social connections and local agricultural innovations were informed by the SLF and the adaptive cycle. These general guiding questions helped initiate fruitful and rich discussions around each topic, allowing every member to contribute to the discussions. Follow up questions on discussions amongst farmers on each of these activities ensured that each of the themes was covered in depth and exhausted before moving on to another theme. After each of these discussions, findings were discussed with farmers to avoid misinterpretation or provide an opportunity for additional comments.

Table 3.1 Attendance and number of group discussions on four study objectives

Group name	**Average attendance**	**Soil & environment**	**Livelihoods**	**Institutions & social capital**	**Experimentation & extension approaches**	**Total**
Mtavu	31	3	3	2	1	9
Kapata	14	2	3	2	1	8
Malaya Nkhata	5	2	2	2	1	7
Chikwina	21	3	2	2	1	8
Jalanthowa	9	2	2	2	1	7
Chipapa	10	2	2	2	1	7
Total		**14**	**14**	**12**	**6**	**46**

Proportional piling and ranking

This technique was used to compare DBF and CR contributions to farmers' food security, income and other household livelihood needs (Objective 2). This exercise made use of marker pens, A2 sized paper and grains of maize. Farmers were asked to draw several circles, representing each aspect of their livelihood aspirations which were further grouped into larger categories. These categories were given abbreviations which were written down inside each of the circles drawn. After this, each participant was given ten grains of maize to be placed in the circles, one farmer at a time and going from one group of livelihood aspirations to another. Each of the farmers had ten grains of maize to put in one circle at a time where the number of grains (Figure 4.9) represented the contribution of the DBF to their livelihoods: 0 “no contribution at all”, 1-2 “negligible”, 3-4 “slight to average”, 5 “average”, 6-8 “significant” and 9-10 “very significant”. Participants were asked to provide reasons for the number of grains put in any of the circles to provide context.

Figure 3.9 Proportional piling and ranking activity with Mtavu farmers.

Flow charts and timelines

Flow charts were used to collect data about sequences of farm activities in both DBF and CR (Figure 3.10). These charts help condense substantial amounts of information into visual representations, revealing useful information that would otherwise remain concealed in questionnaires. Each activity was followed by detailed discussions that revealed more information duration, timing, and other details about each farm activity under DBF and CR. To show a sequence between the activities, arrows were drawn with arrow direction indicating transition from one farm activity to another.

Figure 3.10 Flow chart by Kapata farmers illustrating activities in DBF.

In-depth interviews

This technique was used to understand impacts of DBF on household livelihoods (objective 2), their social capital and local institutions (objective 3), and farmer experimentation and innovation (objective 4). Twelve farmers whose plots were used for soil monitoring participated. Depending on the responses of each farmer, follow up questions were asked to understand a particular emerging theme, process, or issues. During these interviews farmers also used diagrams, visual demonstrations, and illustrations to make their points clear. Participant observation in farmers' homes and fields was a key part of these interviews and strengthened existing rapport, sharing experiences they would not talk about in group setting. Activities included shelling maize, planting and watering crops, maize harvesting etc. Table 3.3 below summarises the number of in-depth interviews that included transect walks, observations, and diagrams and illustrations.

Table 3.2 In-depth interviews conducted in six communities with twelve farmers.

Group Name	**Number of interviews**	**Duration in hours**
Mtavu	2	4
Kapata	2	4
Malaya Nkhata	2	4
Chikwina	2	4
Jalanthowa	2	4
Chipapa	2	4
Total	**12**	**24**

Transect walks

Transect walks and mapping were done as a follow-up to in-depth interviews or group activities. Six transect walks were undertaken in each community; four with the two farmers during in-depth interviews and two with each group after discussions. This covered various issues such as indicators of soil quality, places with crops of interest, experimental sites for new crops and farming systems (Objective 5; Chapter 8) and water sources, including dimbas and grazing areas.

Illustrations and diagrams

Farmers used illustrations and drawings that made sense to them to explain, provide more details or to illustrate concepts, processes, actions, and objects that seemed complex to express in words. During group work, this was an open exercise where every farmer had the chance to make their own understanding of a topic at hand. Despite having to facilitate, the researcher or group leadership did not instruct anyone what to draw, making the process voluntary and inclusive. Illustrations proved useful since some members could not read or write.

3.4.3 Study 3: Social capital and Local institutions

The third objective was to explore and analyse the contributions of Tiyeni's extension approach to farmers' social capital and local institutions which are important parts of the

SLF and form core concepts of adaptation, resilience, and sustainability. To do this, ego-net analysis, an actor-centred social network analysis (SNA) approach (Crossley et al., 2015) was used. In this, each Tiyeni club and individual farmers were considered as actors (ego) in their own capacity. The study sought to explore and analyse ego's connections (alters) that have significant relationships with the ego by combining two distinct techniques of data collection techniques called Name and Resource Generators (Appendix 5) (Smith et al., 2014; Crossley et al., 2015: p. 45). The name generator asks questions to generate names of the alters (connections) that show who the ego is connected to, the structure of the social network and strength of the network. The types of relationships were specified (see Crossley et al., 2015) to ensure that only relationships relevant to this research were cover (Appendix 5). Venn diagrams and in-depth interviews (see above) were the major data collection techniques for Study 3. A total of 18 egos were analysed.

Venn (chapati) diagramming

This technique was used to collect social network data on a club level as guided by a Name Generator. Firstly, a large circle was drawn in the middle of the large paper which represented their club. Secondly, farmers were asked to write names of various institutions, groups, organisations, families and individuals on the rectangular pieces of paper of different sizes. Lastly, the cards were placed outside of the circle drawn on the large paper. The distance between any specific cards to the large circle represented the influence and closeness of those institutions/individuals to that group with those nearest being those with whom they interact with the most or are based near their community. In some cases, these cards were placed inside the circle (Figure 3.11) to show that the institutions or individuals were fellow group members.

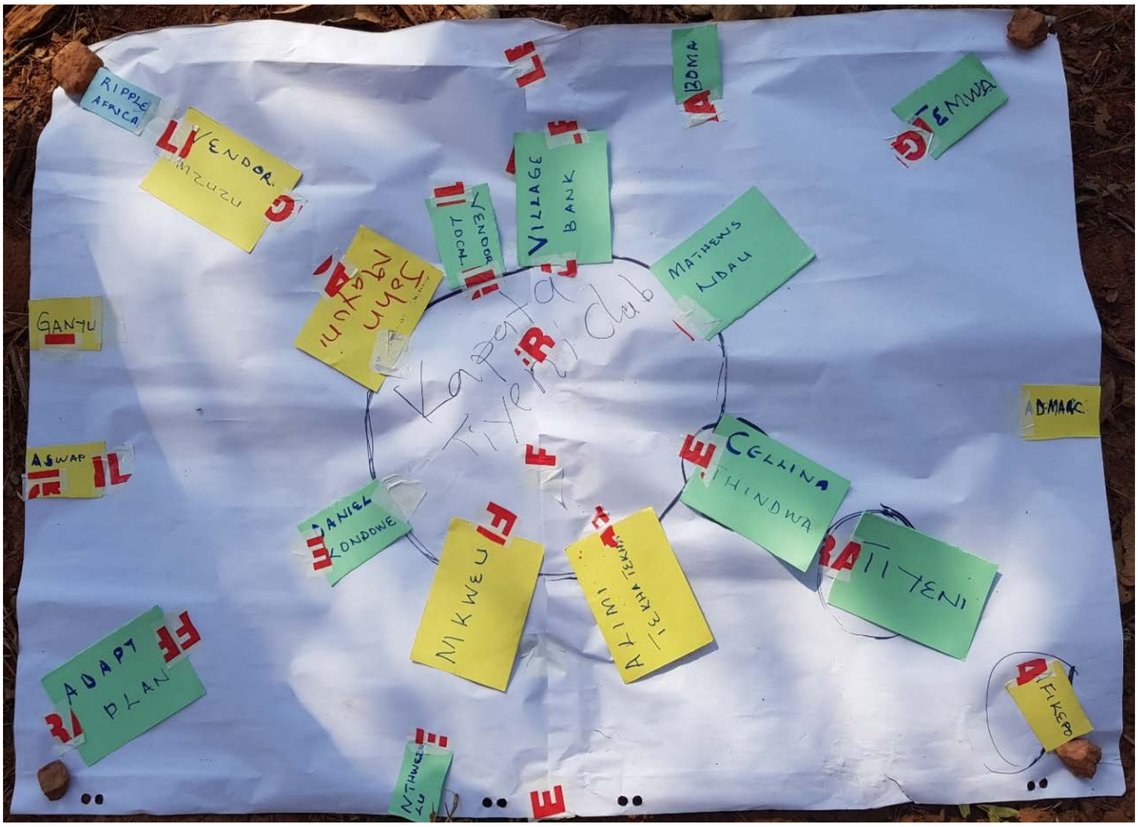


Figure 3.11 Venn diagram made by Kapata farmers detailing their connections.

3.4.4 Study 4: Farmer experimentation: adaptation and resilience

The fourth objective explored and documented farmers' experiments which is important for building smallholder farmers' resilience against the ever-increasing changes in the social-ecological system they are part of (Sections 3.2) and hence contributing to sustainability of both ecosystems and livelihoods (Studies 1 and 2). In-depth interviews before and during transect walks and field observations were the main data collection techniques.

3.5 Data analysis

Data analysis was undertaken in three stages. First, all data, both qualitative and quantitative were transcribed into Microsoft Word and Excel files from their original formats which included farmers' drawings/diagrams and notes, audio recordings and field notes. Secondly, quantitative, and qualitative data were analysed separately after data cleaning, which involved identifying missing data values or misplaced items in the datasets. The last data analysis phase is the comparison and integration of the two types of data, a process called mixed methods data analysis (Creswell & Creswell, 2018). This involved merging and comparing the results in the discussion sections of each chapter.

3.5.1 Study 1 data analysis

On-farm soil and erosion monitoring data were used to test the hypothesis that there are no differences in soil quality status, soil erosion rates and maize yields between DBF and conventional ridges in farmers' fields in northern Malawi. Paired soil property laboratory results, maize yields and soil erosion data were analysed to test for differences between the DBF and contiguous CR and relationships among variables using Mann-Whitney U Test and Principal Component Analysis (PCA), respectively, using Statistical Package for Social Scientists (SPSS). To test the effects of type of tillage and depth on water infiltration, soil organic matter and soil carbon, Pearson's correlations (Pearson's r) was performed using the same software (SPSS). Due to the small sample sizes (plots), comparison of means across communities was not a necessary computation and thus has not been included in this study.

3.5.2 Study 2 and 4 data analysis

Studies 2 and 4 were qualitative in nature hence much of the data analysis followed content analysis procedures (Miles and Huberman, 1994; Kawulich, 2005; 2011; Denzin & Lincoln, 2005; 2011; 2018). Four distinct stages were followed: 1) narrative, 2) coding, 3) interpretation, 4) confirmation and 5) presentation. As explained under Section 3.5, the first phase was the transcription and translation of data from field notes, interviews, group activities and audio recordings for each activity into word format, organising the data into narrative components following study themes. Transcribed data were imported into Nvivo for coding and reorganisation into study themes and emerging stories. To make sense of the codes, study themes, theoretical frameworks and data were reviewed. This third stage also helped to triangulate findings through cross-examination of data collected using different techniques, which helped to confirm conclusions drawn from the data and the analysis process.

3.5.3 Study 3 data analysis

Data analysis for study 3 follows a description of the data analysis process for Ego-Nets by Borgatti (2013: 217) and Crossley et al. (2015: 76-104). UCINET was then used to provide descriptive measures for each ego-net, namely:

1. Tie Central Tendency which measures and compares the number of alters for each ego, before and after joining the Tiyeni group.
2. Tie Dispersion which measures the distribution and variation of ties.
3. Structural Shape which measures the relationships amongst ego's alters and provides ways of determining strength of the ego-net (Burt, 1995).
4. Ego-Net visualisation using NetDraw, a computer function embedded within UCINET. These visuals are important for showing the changes of ego's social capital over time.

3.6 Challenges and limitations of data collection

Both the 2018 and 2019 exercises were not without logistical and technical challenges. Among these challenges, unmet farmer expectations were the major problem. Due to the previous CA and Tiyeni projects giving handouts in form of fertilisers, seeds and herbicides, many farmers expected the same treatment. This led to decreasing enthusiasm and attendance in group activities for some farmers, a typical challenge in participatory research since the 1990s (Cornwall & Jewkes, 1995). Dominant members in all these six groups were also observed. To some extent, the facilitator (the researcher) was able to control this by selecting different members to answer a question without offending the dominant ones.

Like experiences by Hockett and Richardson (2016), field operationalisation of experimentation, adaptation, and resilience themes was particularly challenging given the lack of better terminologies that could convey the same message in Tumbuka language. To counter this challenge, explaining these concepts in more detail was the emphasis of every activity. Consequently, it took more time to facilitate group activities that involved these themes.

In terms of environmental monitoring, the biggest challenge was theft of materials, especially plastic papers. These communities still have grass-roofed houses which rely on plastic sheets to prevent leaks. The field officer had to constantly move between sites to replace the stolen material which increased project costs.

Lastly, group activities coincided with community engagements like community development works, other group meetings with other organisations and projects or weddings, funerals, and illnesses. Due to these, activities could be cancelled and rescheduled. This meant extending project timeline. Due to the flexible nature of this research, such changes did not have significant impacts on this work.

Like most interdisciplinary studies, maize yield findings and other soil variables need to be considered in the light of some limitations arising from the research design used. Because the overall interest of the study was the variations occurring across time and study sites in addition to the need to strike a balance between the social and ecological aspects of the study as well as time and financial limitations, the use of the Space-For-Time substitution concept (Section 3.3.2) was necessitated. The concept assumes equivalent temporal and spatial variations of ecological parameters. While contiguous two- and five-year DBF and CR plots were established on the same farm with similar soil characteristics, land use history and weather to minimise problems arising from site-specific issues, the fact that the study sites themselves are some kilometres apart may have introduced unintended limitations in attributing differences across plots to duration of DBF use.

Ecological changes are complex and non-linear, with variations at all scales of measurements, from the plot level, farm, community etcetera. Because of the long distances from one study site to another, variations due to differences in soil types and fertility, rainfall and temperature, topography, and social-cultural factors may have an influence on maize yields and soil parameters. To reduce such limitations, future research can aim to reduce the distance between study sites by running several separate studies. These could then be used in a meta-analysis that amalgamates key findings from study sites of differing social-ecological conditions, assuming availability of time and financial resources.

Chapter 4

The social-ecological characteristics of the study sites

Chapter overview

This chapter presents environmental and socio-economic description of the six study sites based on the information gathered during a scoping visit done in June 2018. This is done to contextualise results and discussions in the subsequent chapters and to help show and explain variations of key findings among the six communities, across time (2 to 5 years), and among farmers. The chapter also provides key foundation on which synthesis of site-specific sustainability of the Tiyeni DBF in Chapter 9 rests. Besides description at community level, the chapter further introduces and describes key informant farmers who volunteered to have on-farm experimental plots.

4.1 Location of the study sites

A preliminary study in June 2018 identified study communities with two and five years' DBF experience within a 45km radius of Mzuzu City in northern Malawi (Figure 4.1). The 45km radius provides an area with dense DBF activities where both two- and five-year-old DBF farms are located. From Tiyeni records, there were seven groups with two years DBF experience and nine groups with five years DBF experience by June 2018 within the 45km radius Tiyeni catchment area. Twelve familiarisation visits were made to these sixteen communities (June-July 2018) to understand the types of communities and farmers involved and to build rapport. This was also the time to navigate the various possible challenges including logistical challenges.

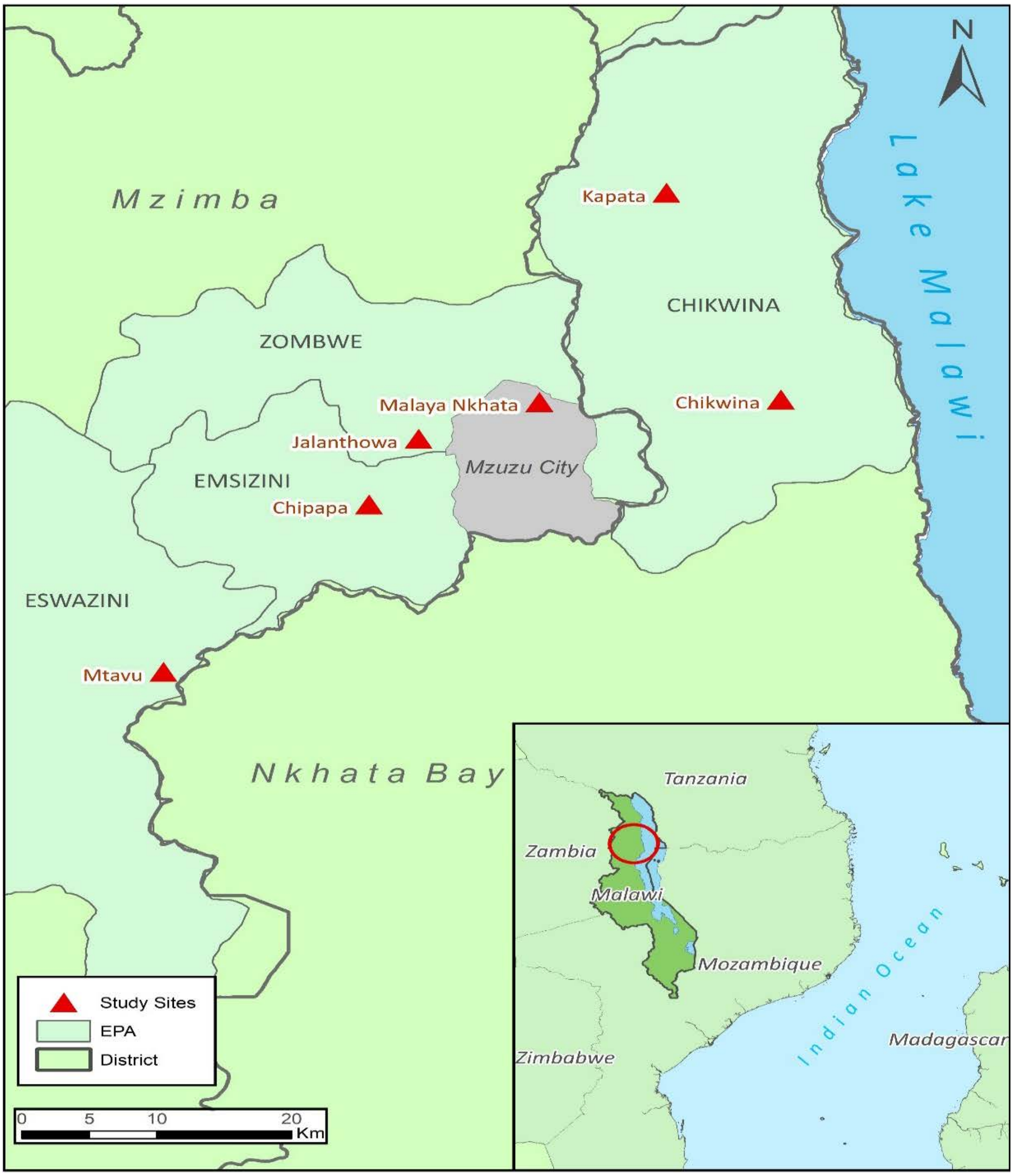


Figure 4.1 Location the six study sites in northern Malawi

It was revealed, however, that some registered groups were not functional; for the five-year-old groups, five groups were non-existent while the sixth group was not functional as the rest of the members left the group due to various group disputes. Of the seven groups in the two-year category, two groups were non-existent on the ground whereas the other one had just begun with less than a year of DBF experience, remaining with four groups. Two of the four remaining groups were of the same families who had split the original group (Malaya Nkhata) into two. One of them was chosen to have three groups in the two-year category. Three groups remained in each category, totalling to six study sites namely Kapata, Malaya Nkhata and Mtavu in the two-year category and Chikwina, Jalanthowa and Chipapa in the five-year group (Table 4.1).

Table 4.1 Location of study sites and number of participants

Category	**Group**	**Coordinates**	**Gender**		**Total**	**Percentage**	
			Female	**Male**		**Female**	**Male**
2-year-old sites	Mtavu	11º36’12.677’’S 33º45’53.013’’E	31	31	62	50	50
	Kapata	11^{O}12’01.157’’S 34^{O}06’03.539’’E	15	14	29	52	48
	Malaya Nkhata	11º22’38.464’’S 34^{O}00’57.402’’E	3	7	10	30	70
5-year-old sites	Chikwina	11º22’56.457’’S 34^{O}10’05.731’’E	9	6	15	60	40
	Chipapa	11^{O}28’09.599’’S 33^{O}53’59.573’’E	10	11	21	48	52
	Jalanthowa	11º24’35.051’’S 33^{O}56’04.746’’E	10	8	18	56	44
Cumulative			78	77	155	50	50

The six study sites fall under Nkhata Bay district (Chikwina and Kapata) and Mzimba (Jalanthowa, Mtavu, Chipapa, and Malaya Nkhata) under Mzuzu Agricultural Development Division (Mzuzu ADD). Whilst sharing boundaries, the two districts differ in terms of environment and socio-economic characteristics. Nkhata Bay is characterised by high annual rainfall amounts of over 1500mm spread across eight months (October to May/June) with varying amounts in various locations given the district’s hilly terrain (Malawi Government, 2017). Prominent in the district are its steep slopes, close network of hills and perennial streams in the north and relatively flat planes, sparsely distributed mountain ranges and extensive wetlands (along Limphasa valley) in the southern half. Correspondingly, the mountainous north is characterised by ferrallitic soils which are shallow, well drained but less fertile unlike the dark, well drained, and fertile lithosols along valleys and farther south (Malawi Government, 2017; Snapp, 1998).

According to NSO (2018), the district has a population of over 280,000 people with population density of 68 persons per square km which is one of the lowest population densities in the country. The district is populated chiefly by Tonga tribe which makes up over 65% of the total population, and Tumbukas in the north who constitute over 33% while the rest are tribes that migrated from other districts. The main economic activity, like the rest of the country, is subsistence agriculture with over 65,000 farming families where cassava is the staple crop among the Tongas while some northern Tumbuka populations depend on maize. Other notable crops in the district include rice, sweet potatoes, potatoes, millet, tobacco, sugarcane, legumes and macadamia nuts, tea, and coffee for large scale estate owners. Wetland cultivation is an important coping mechanism to rainfed crop production and provides crucial source of income and food for smallholder farmers. According to Njoloma et al. (2016) and Shaxson et al. (2014), the district is prone to soil erosion by water given its steep slopes and susceptible soil types such that it loses an average of over 30 tons/ha/year.

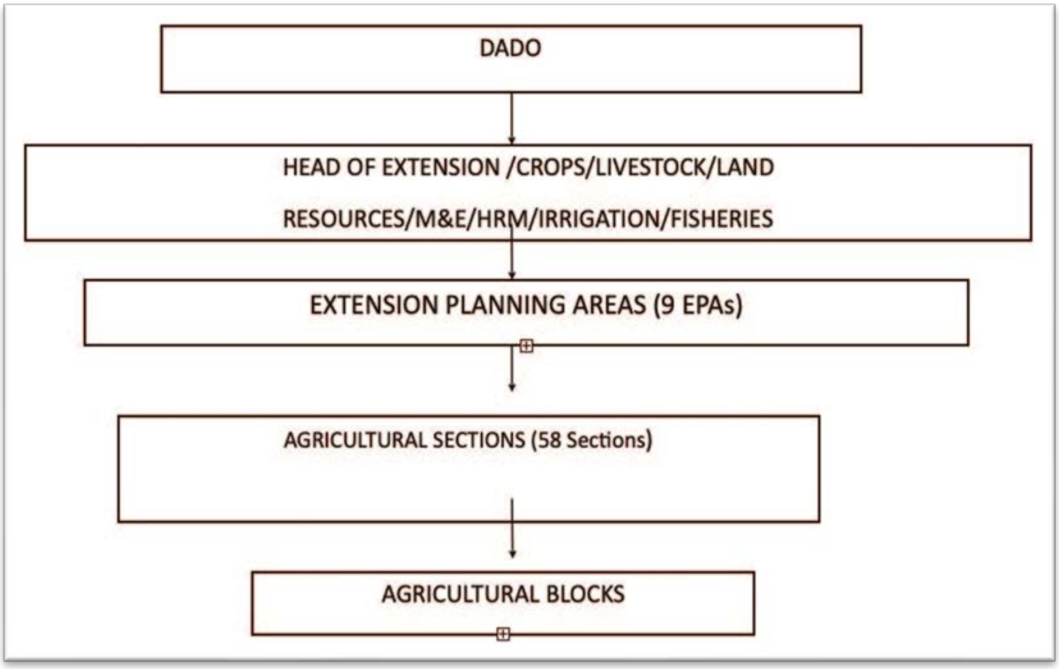


Figure 4.2 District level agricultural extension hierarchy (Malawi Government, 2017).

Administratively, all districts in Malawi fall under Ministry of Local Government and Rural Development constituted by the Local Government Act of 1998 amended in 2010 comprising various ranks and committees that oversee various functions of the district council. In terms of agriculture, the overarching unit is Mzuzu ADD where both Mzimba and Nkhata Bay District Agriculture Development Offices (DADO) fall. Figure 4.2 shows the agricultural development hierarchy in Malawi.

Figure 4.3 Location of Mzimba and Nkhata Bay

Mzimba district borders Nkhata Bay to the east, Kasungu in the south, Nkhotakota in the southeast, Rumphi in the north and Zambia to the west (Figure 4.3). Unlike Nkhata Bay, Mzimba district is relatively undulating with the Vipya plateau and other hills representing highest points above sea level (1954 m.a.s.l.) with extensive plains to the western section (Malawi Government, 2017). Rainfall averages 900mm per annum between November and March with some places receiving depending on topographic features. Light to moderately textured eutric-fersialic soils that are fairly fertile are characteristic of the district, allowing the growing of wide range of crops.

Ngoni and Tumbuka tribes dominate the district whose main livelihood activities include rainfed farming of maize (staple crop), legumes, livestock, timber and non-timber forest products, retail trading, and small-scale mining (farther south). Other crops include cassava, potatoes, fruits and vegetables. Tobacco remains a key cash crop in the district despite its prices deteriorating for the past decade. According to Sileshi et al. (2014), the district suffers from soil fertility degradation and loss of topsoil because of unsustainable farming techniques that leave the soil exposed to erosive forces of rainwater and wind. Continuous monocropping has also been cited as being on the rise given the rapid population increase in the district (Sileshi et al., 2016; Malawi Government, 2017). These challenges are also worsened by the impacts of climate change that have so far manifested in the form of reduced rainy days, unreliable onset and cessation of rainfall, increased incidents of heavy rainstorms and number of droughts and dry spells among others (Malawi Government, 2017).

4.2 Chikwina

Chikwina is some 45km from Mzuzu City with the nearest town being Mpamba about 25km south in Nkhata Bay district in Sub-Traditional Authority (ST/A) Nyaluwanga with Tonga being the main tribe. It is characterised by very steep slopes (Figure 4.4), the lowest points being wetlands (dambos) with perennial streams. The area is only accessible through two earth roads; one that connects the area with the north eastern Mzuzu and another from Mpamba trading centre off M5 road. It is connected to Mpamba and Mzuzu by two earth roads that become near impassable in the rainy season. The community receives over 1600mm annual rainfall (Malawi Government, 2017) which coupled with steep slopes and poor farming techniques exacerbate soil erosion and degradation.

Figure 4.4 Steep slopes, cassava and dimba cultivation in Chikwina

As a staple crop, cassava covers over 80% of the land under rainfed agriculture followed by maize and legumes. Unlike communities in Mzimba, Chikwina farmers normally grow maize for income and as a safety net should cassava fail because of diseases. While the community grapples with significant soil erosion, rainfall patterns and amounts per year remain dependable. As of 2019, there were at least 22 NGOs like Tiyeni providing similar or slightly diversified agricultural extension messages. Recently, banana cultivation has become famous with the involvement of Afikepo project that provides free hybrid sackers (planting materials), pesticides and markets. Figures 4.5 and 4.6 show average household sizes and education levels among participants from each study sites.

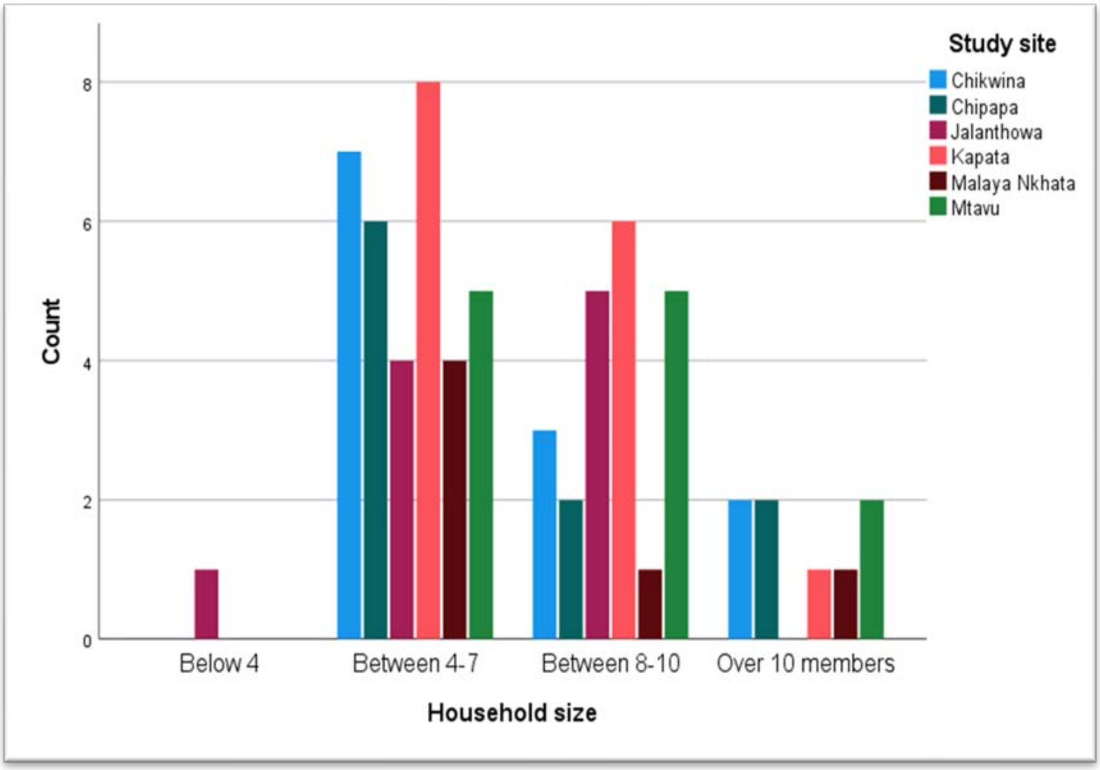


Figure 4.5 Household sizes by study sites (using data from 2018 preliminary study)

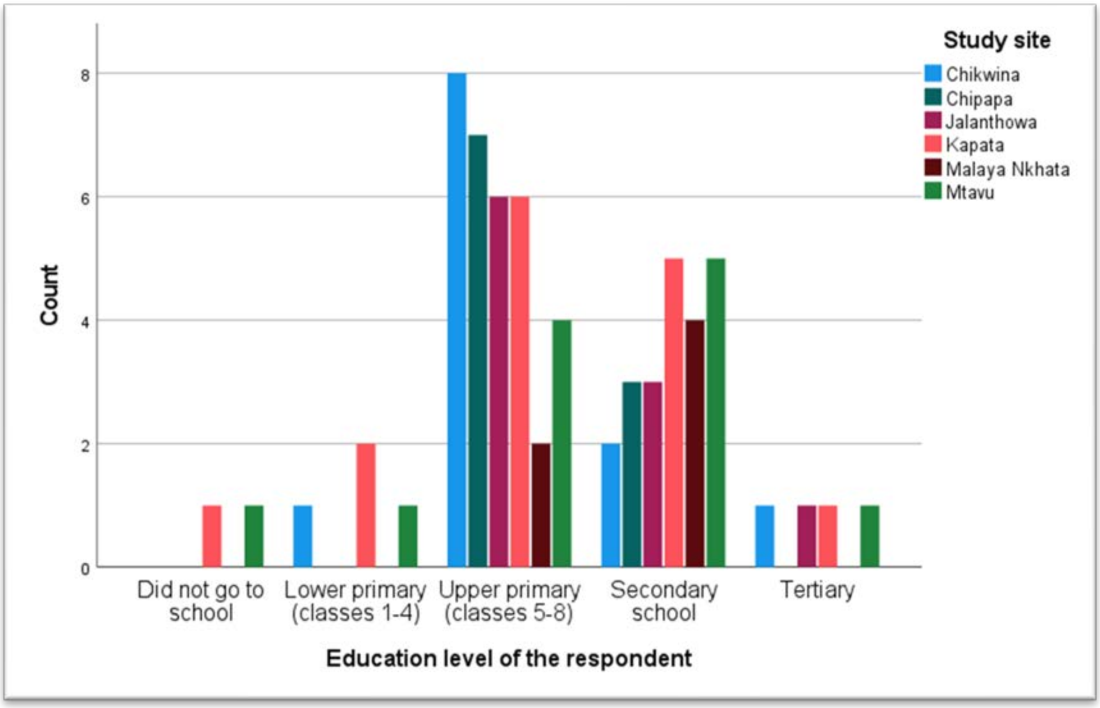


Figure 4.6 Education level by study site (using data from 2018 preliminary study)

Key informant farmers

4.2.1 Farmer 3EMC

Farmer 3EMC is a member of the Chikwina Tiyeni club who grew and attended his school in Zambia before his parents moved back home in 1982. He worked in the hospitality industry in Blantyre where he also attended college. He has also held a number of key public positions in the community upon his return to Chikwina in 1995 like VDC, ADC chairperson, Ward Councillor, lead farmer, etcetera, which combined, have made him an influential individual. His main livelihood activities include cassava growing for food and income which he intercrops with other crops like maize, legumes, potatoes, leafy vegetables and bananas as well as maize, legumes, bananas, vegetables in the dimbas and small-scale grocery shop. Over 90% of his actively cultivated land is under cassava production. He also owns town houses in Blantyre which give him a monthly income from rentals besides his monthly gratuity pay. Despite not having enough family labour for his agricultural activities, he often hires labourers given his stable monthly income.

Unlike other farmers, his DBF plot is in the wetland (Figure 4.7) prone to soil erosion and washing away of crops from upland runoff. Field observations showed that the plot is constantly wet given its location and high rainfall amounts which necessitates making of drainage systems to let extra water out and allow crop growth in the rainy season. The plot has dark, well drained and deep clayey soils, typical of wetlands and areas closest to them. The plot does not have box ridges given that he needs to keep water out of it.

Figure 4.7 DBF plot in a wetland. Its location also makes it prone to runoff from upland.

4.2.2 Farmer 3GPC

Farmer 3GPC is a member of the Chikwina Tiyeni club since 2014 when Tiyeni first introduced themselves and the DBF through Donald Mtambo. She was born, raised, and married in this area (1963 to date). She owns land by marriage and has seven children and ten grandchildren with four orphaned grandchildren under her care. She is also a member of various other farmer clubs, but she does not hold any central positions in any of them. Her main livelihood activities include subsistence farming where cassava is the main crop for both food and income supplemented by maize, legumes, tomatoes, potatoes, and sweet potatoes for income. One of her biggest challenges is sourcing farm labour given her age which worsens when she gets sick or travels out of Chikwina.

Her DBF plot is located on a very steep slope, making it prone to high levels of soil erosion and the resultant soil fertility degradation and downstream damage to wetland systems. The plot is demarcated into small pieces using large contour ridges which are planted with vetiver grass that reinforce the ridges. Given her limited labour, this plot is the same size as when she started DBF in 2015. Because she undertakes all activities herself (on DBF plot), manure making is not one of her priorities and when she can, raw animal dung is applied. It was also observed that beds were not of the same dimensions where others were more or less than 1m wide. Also, noted were deeper and larger box ridges than 30cm. Signs of previous crop residue retention were visible, but the practice is not consistent for the same reason as manure application.

Table 4.2 Main income sources among the 12 key informants

Farmer	Rainfed	Dimba	Employed	Remittances	Small Business
2WMM	72000	20000	0	0	0
2KMM	0	130000	12000	0	0
3EMC	300000	190000	60000	50000	80000
3GPC	80000	30000	0	30000	40000
1GNC	12000	5000	0	0	30000
1MMC	20000	10000	0	40000	25000
4DMJ	500000	40000	0	0	300000
4LCJ	45000	8000	0	0	30000
5CTK	160000	80000	264000	0	50000
5DKK	300000	15000	250000	10000	200000
6MNM	150000	500000	0	0	50000
6TNM	0	800000	0	0	100000

4.3 Kapata

Kapata is an area located in Bula agricultural section under Chikwina EPA in Nkhata Bay north, Traditional Authority (T/A) M’bwana, 45km north of Mzuzu city. Unlike in Chikwina, Kapata is dominated by Tumbuka people who have also welcomed other tribes from other districts of the country. The area is largely untampered with most of the land under natural rainforests. Because of this and the warm-hearted people of the area, the area is slowly becoming populated by people relocating from Chitipa among other places. The area is characterised by hilly terrain with steep slopes as well as high rising mountains to the west with some valleys along the north end of area. Soils are mostly ferrallitic which are shallow but fertile with some sparsely distributed fertile loamy clay along streams and valleys. Because the area is farthest from any major town like Mzuzu, access to markets and other services is problematic.

Major challenges facing crop production include soil erosion and degradation because of steep slopes and poor cropping techniques that expose bare land to erosive forces of rainwater. Occasional occurrence of crop pests such as worms and other crop pests have also been cited by farmers. Roaming livestock and wild animals (e.g., monkeys, birds, and warthogs) worsen farmers' plight as they often destroy succulent stems of young crops or nearly mature ones for plots located along the western section of the community near high rising mountains. While rainfall amounts have not significantly changed to affect crop production, onset and cessation of rains have been cited as some of significant changes.

Key informant farmers

4.3.1 Farmer 5DKK

Farmer 5DKK was born and raised in Usisya, some 30km east of Kapata in Nkhata Bay where he also attended his primary education. Before being given free land by his friend to become a full-time farmer in Kapata (Bula), he worked as a civil servant for 27 years and retired in 2004. As of 2019, his household had eleven members, three of them being grandchildren under the age of 10. To supplement his income from formal employment, he began growing tobacco in 2004 which he continues to do despite poor prices for the crop. He is a member of several farmer groups where he holds leadership positions. Tobacco remains the mainstay of his annual income besides monthly pension pay (Figure 4.8), rainfed and dimba cultivation. Labour shortages due to insufficient family labour and the labour demanding tobacco enterprise constitute major livelihood challenges.

His DBF plot is located on a slightly sloping land with greyish sandy-loam soils which are good for a variety of crops. He still burns crop residues and dry weeds on his plot except where he needs them for preparing tobacco nursery beds. Close observations revealed a number of missing key features of the DBF like box and contour ridges, crop residue retention, organic manure application and vetiver grass. Moreover, his seed beds were very shallow, 10cm or less (Figure 4.9), while some of the beds were wider than Tiyeni recommendations. Despite being only two years old, bed surfaces were already compacted, crusted and sealed.

Figure 4.8 Farmer 5DKK's almost flat deep beds plot with no mulch.

4.3.2 Farmer 5CTK

Farmer 5CTK was born and raised away from home (Bula) where she was educated and employed in the civil service in Lilongwe until her retirement in 2013. Because she did not grow up in Kapata, she has found it difficult to assimilate with the locals such that she gets left out of many development projects. She and her sister own over 30 hectares of land which they inherited from their father. To secure her vast unused land from encroachers, she practices shifting cultivation to let others know the land belongs to her (Figure 4.10). Besides a stable monthly income from her former employer, Celina is an accomplished smallholder farmer who grows maize and beans in the slopes and cabbage and other vegetables in the dimba.

Figure 4.9 Farmer 5CTK’s shifting cultivation plot in the middle of the forest.

Unlike most farmers in Kapata, she has access to profitable markets for her crops because of her social connections in government departments and private companies. She also owns cattle, goats, pigs and chickens which provide extra income, manure and meat (Figure 4.11). Steep slopes necessitate making of contour and box ridges and vetiver grass planting on her DBF plot. Similarly, fertility degradation and need to cut out buying inorganic fertilizers make it profitable to retain crop yields and make and apply manure on both DBF and CR plots. According to her, pest problem is the reason why she grows tephrosia as an insecticide. She has fully aligned her DBF practice to Tiyeni standards except growing of hybrid seeds (Figure 4.12).

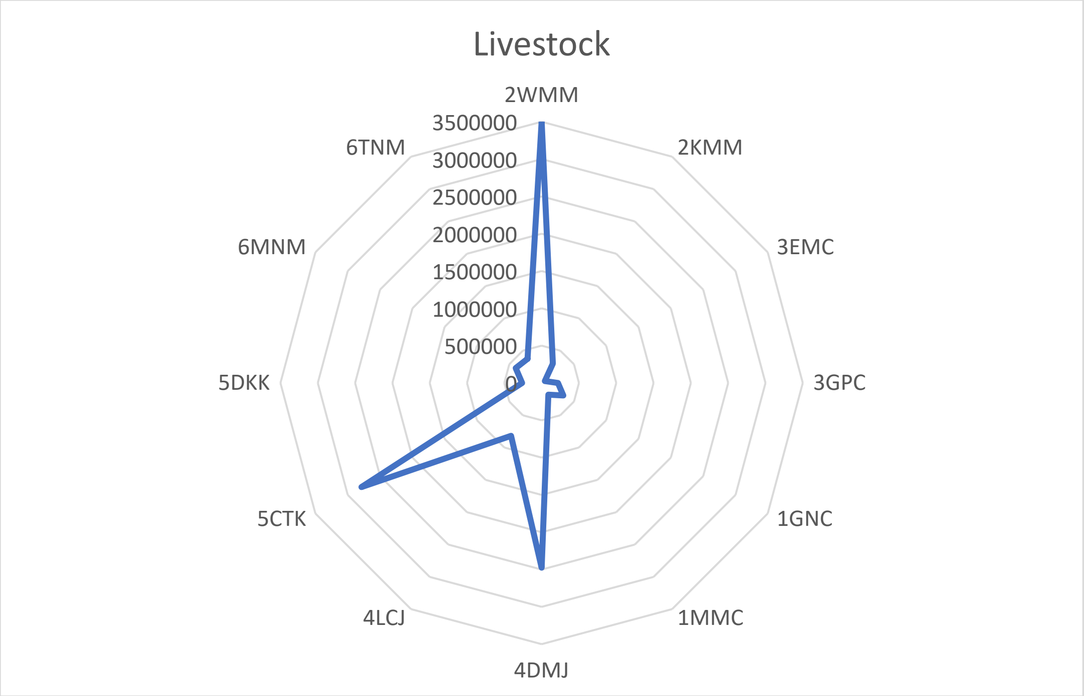


Figure 4. 10 Livestock standing value in Malawi Kwacha (from own data)

Figure 4.11 Farmer 5CTK's fully aligned DBF plot (crop residues, box and ridges and vetiver).

4.4 Malaya Nkhata

Malaya Nkhata village is closest to Mzuzu city located about 10km north along Mzimba-Nkhata Bay boundaries. The area is flat with several perennial streams that form continuous networks of fertile wetlands. However, upland soils are unsuitable for a range of crops because of their high sand contents (Figure 4.14), making dimba cultivation a principal source of food and income than rainfed agriculture (Figure 4.13). The soil type also influences the type of vegetation where *Brachsytegia taxifolia*, *Strychnos spinosa*, *Uapaca kirkiana* and some grass species are dominant vegetation types.

Brick making and selling is a vibrant income generating activity besides rainfed and wetland farming given the area's proximity to Mzuzu. Consequently, deforestation from fuelwood for brick curing and charcoal production has been on the rise. On the other hand, proximity to the city means that farmers in this area easily sell their crops and livestock. Soil erosion is not a problem given that their land is relatively flat and because soils are mostly sandy which allows rainwater to infiltrate quickly. Likewise, no significant rainfall variability has been cited by farmers.

Figure 4.12 Sandy soils with cassava in Malaya Nkhata

Key informant farmers

4.4.1 Farmer 6TNM

Farmer 6TNM is a 56-year-old man married to two women with whom he has 9 children. His main livelihood activities include making and selling bricks to construction companies from Mzuzu besides rainfed and wetland cultivation. He began brick making and selling in 1980 before he married his first wife. Investment capital comes from dimba cultivation which also contributes the largest to his annual earnings and household food security. He owns large piece of land some of which remains idle, forested, or rented out for money. He also used to grow tobacco but stopped due to poor markets and its labour-demanding nature. Because of the soil's poor fertility, he has been constantly searching for livelihoods diversification strategies ranging from dairy, poultry, and most recently, fish farming.

His DBF plot showed that there was inadequate tillage as beds looked shallow and flat. There was no sign of contour and box ridges, crop residue retention or manure application. According to him, he spends much of his time in the dimba and brick making which give him more money than rainfed farming in the slopes. Similarly, manure from his cattle, goats and chickens is also used for wetland cultivation such that little is left for DBF plots. While rainfed farming still provides him with some food, wetland cultivation gives him enough income to support his family and a daughter in college.

4.4.2 Farmer 6MNM

Farmer 6MNM is an active member of the Malaya Nkhata Tiyeni club whose livelihoods depend on dimba cultivation, rainfed agriculture, brick making, sale of livestock and running a small grocery shop. Despite brick making being a lucrative and less risky business, his busy schedules that involve traveling to various places for church activities make it difficult to fully engage in this activity. Given the poor soil fertility upland, he invests his limited time and labour in dimba cultivation where he gets most of his income and food. Being a third born in a family of six, the death of his father led to land disputes among his siblings. As per the custom in this area, the eldest son had more authority in the redistribution of land, keep most of the more fertile land to himself and leaving others to share the rest. While the community already has infertile sandy soils, this dispute led to Madalitso and his younger siblings having the least fertile of their father’s land.

His DBF plot does not have contour and box ridges and vetiver. Most of the beds are also wider and deeper than Tiyeni's recommendations and most of them are planted with cassava. He does not apply manure because of other competing needs for the manure and labour and his endless travelling to various places for church activities where he also learns new ways of farming. Crop residues are retained on bed surfaces, but some of it is fed to his livestock.

4.5 Jalanthowa

Jalanthowa is a village located about 10km away from both Mzuzu and Ekwendeni in the Zombwe EPA (Figure 4.16). There are no steep slopes in the area with gentle to undulating terrain across the community. soils are brownish in colour, showing the high contents of iron and oxides. The clayey loamy soils are good for growing a variety of crops such as maize, legumes, cassava, tobacco, among others. Almost all natural forests have disappeared in the area due to brick curing, charcoal making and rapid population growth that forced many households to clear most of their idle forest lands into agricultural plots.

Much of the soil degradation happening in this area is due to poor cropping techniques, loss of forests, monocropping and continuous cultivation that deplete certain soil nutrients important for crop growth. Such challenges are also exacerbated by significant shifts in rainfall such that patterns are now unpredictable; the area may have heavy rains, dry spells, and droughts at any point unlike in the past when farmers could predict such occurrences. Because of the loss of natural forests in the area, it is now becoming a common practice for farmers to plant blue gum trees (*Eucalyptus globulus*) around their land plots or along boundaries with others. Brick making and selling besides subsistence farming forms a crucial livelihood activity in the area. Its proximity to towns (Mzuzu and Ekwendeni) gives it an advantage to easily access markets for crops, livestock, and inputs unlike other communities.

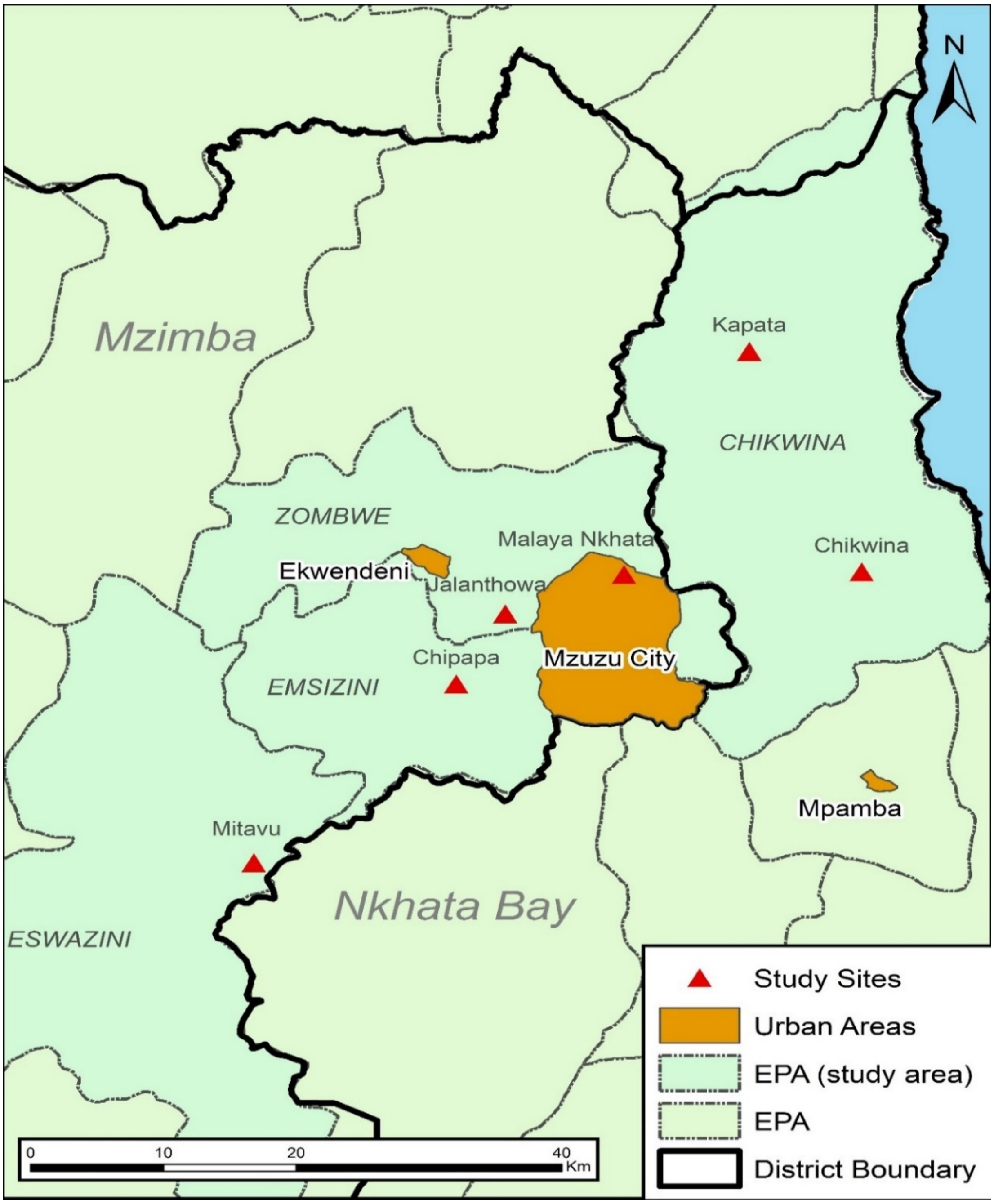


Figure 4.13 Locations of Extension Planning Areas (EPAs)

Key informant farmers

4.5.1 Farmer 4LCJ

Farmer 4LCJ is 66 years old who takes care of 4 grandchildren left by her late daughter. Despite her advanced age, she has to provide for her family including her aged husband. She does this through making and selling cured bricks which are sold to individuals and companies from Mzuzu and Ekwendeni for their construction. Additionally, rainfed agriculture is the main source of food supplemented by wetland cultivation. Major challenges to her livelihoods including shortage of labour, soil fertility degradation from monocropping and over used land. She has been in involved in many agricultural development projects besides no-till and DBF and is still a member of several community groups including a village savings and loan scheme.

Her DBF plot showed that despite the beds still being in use, their condition requires immediate redoing. For example, beds showed to be less than 10cm deep against Tiyeni’s 30cm recommendation or 20cm in CR; surfaces were hard and crusted with apparent hardpans right from the top layers. The plot did not have box ridges or signs of previous crop residue retention. According to her, the only time she applied enough manure on her DBF plot was in 2015 which was also the year she got recognised as the best performing farmer by Tiyeni. However, edges of the plot had contour ridges with mature and overgrown vetiver grass.

4.5.2 Farmer 4DMJ

Farmer 4DMJ is a certified bricklayer in his late 60s who worked in the private sector for over 24 years before returning home to become a full-time farmer in 1995. Unlike many farmers in Jalanthowa, 4DMJ has a large piece of land which he does not manage to utilise at the same. He rents some of it to other people to help them produce some food. According to him, he does not face hunger and does not consider himself poor because he has more than enough food which he gives to other community members for free when they are starving. He also owns cattle, pigs, chickens, goats and pigeons which give him money, manure and meat. Apart from rainfed agriculture, he runs a small grocery shop. Unlike his colleagues, his agricultural income mainly comes from rainfed cultivation (Figure 4.17).

Beds in his DBF plot are around 30cm depth with about 1m wide. However, he does not grow vetiver grass, make manure, and apply it and there were no signs of previous crop residue retention. His serious challenge is labour because all his children are married. Besides, his wife does not like doing dirty work in the farm. He also works to cut on the number of inorganic fertilizer bags he buys per year.

4.6 Chipapa

Chipapa is a community located within Emsizini EPA about 20km west of Mzuzu City. The area has experienced rapid population growth over the past two decades which has put a serious strain on land-based resources especially forest products and agricultural land. As a result, soil fertility has declined. Despite the area being flat, soil erosion has been reported by some farmers with their plots near hills and streams. Naturally, soils in this community can be categorised into major types; sandy-loam to the west and brown clayey-loam to the eastern half. The rapid loss of natural forests has also been exacerbated by curing of bricks that form an important livelihood activity in the area besides expansion of agricultural land as the number of households increase. As the need for land increases, the same land is intensively used for growing the same crop (maize) which has further led to degradation of fertility and increased the need for application of inorganic fertilizers.

Chipapa farmers cited significant changes in the amount and patterns of rainfall as being serious challenges to their agricultural productivity. Chiefly, onset and cessation dates change every year. Droughts and dry spells can strike at any time. Destructive heavy storms can damage crops at any stage of their growth. Likewise, occurrence of pests such as white grubs has increased. Combined, their agriculture-based livelihoods have become riskier and more unpredictable than before. Despite being able to easily access markets owing to their proximity to Mzuzu city, the lack of farmer cooperatives leaves them vulnerable to unscrupulous vendors who offer individual farmers exploitative prices.

4.6.1 Farmer 1MMC

Farmer 1MMC is a 68-year-old widow taking care of three orphaned grandchildren. She depends on subsistence farming for food and income as well as remittances from her son. Labour is also scarce given that she is the only one around and willing to work the farm. With inability to hire labourers, she can only manage to farm a small piece of land. Given her poor economic status, she also struggles buying agricultural inputs such as inorganic fertilizers and hybrid seeds. She has been facing land disputes from her late husband's relatives for the last decades. She also keeps and sells pigs to vendors from Mzuzu in addition to *masuku* fruits (Uapaca kirkiana), avocado and others. Pigs also provide manure for both rainfed and dimba farming. She has been a member of various farmer groups such as those that promoted no-till, basin CA, Afikepo project etc. However, she does not hold any positions in any of these groups.

Her DBF plot is well maintained with bed depth near 30cm, and signs of manure application were apparent. Because her DBF plot is close to a hill, crop residues left on the bed surfaces do not last long because termites destroy them in less than a month, leaving bed surfaces bare such that bed surfaces looked crusted and compacted. Soils on the plot are grey with higher clay contents mixed with loam which is near a small hill. It is fertile when compared to many farmers whose land is often high in sand or iron contents. According to her, she had cut her finger while preparing compost manure in 2015. Since then, she does not make manure.

4.6.2 Farmer 1GNC

Farmer 1GNC has been raising her children and grandchildren on her own since her husband died in 2000. She also makes bricks for sale which enables her to pay for school fees, buy inorganic fertilizers, hire labourers to work on the farm and buy some household basics. Siblings of her late husband have been trying to take her land since the year 2000 besides fending off encroachers on her unused land. Because she is old and raising grandchildren, she always faces labour challenges; from rainfed agriculture, dimba cultivation, brick making, crop marketing and household care. She also sells doughnuts and dried small fish called *Usipa* (*Engraulicypris sardella*) to supplement her income. She is a member of various community clubs including village bank, school development and church welfare. Her DBF plot is located on flat land with well-prepared beds that were 1m wide and nearly 30cm in depth with signs of previous crop residue retention. However, the plot did not have vetiver on contour ridges and box ridges were sparsely distributed.

4.7 Mtavu

Mtavu is located about 40km South of Mzuzu in the western boundaries of the Chikangawa Pine Plantation (See Figure 4.16 above). The area is surrounded by hills that form the transition zone between the tree plantation and the eastern bounds of Mzimba district in Sub-T/A Kampingo Sibande (Figure 4.18). Soils in Mtavu are varied. Areas near streams which have dark, deep, well-drained and fertile soils that support growing of a wide range of crops from maize, legumes, leafy vegetables, onions, and garlic as well as support fish keeping. Those farther upland or close to hills are brownish, shallow, stony and less fertile. Natural forests are still available, but locals said they are disappearing at a rapid rate, prompting some of them to begin reafforestation and bee keeping. Recent trainings in garlic farming and marketing have transformed wetland cultivation into a lucrative business in the area where every household has a garlic plot.

Unlike the other five study sites, Mtavu has stable and functional institutions in the form of farmer groups which are governed by their own local rules and agreements that guide membership to various projects and control garlic and onion prices. Despite being far from any nearest town (Mzuzu and Mzimba), the community has a wide range of customers for their crops. Owing to its hilly location and loss of forests, the location faces increasing soil erosion and the resultant soil fertility degradation and destruction of wetlands which has affected agricultural productivity, food security and income levels. Rainfall patterns in the area have also changed from what the area used to experience three decades ago. According to Mtavu farmers, the area receives different amounts of rainfall every year. It is also difficult to predict when the rains would start or end, making it harder to plan planting dates as it used to be the case in the past. A combination of these reasons has made their agriculture-based livelihoods riskier than the past two decades, making it important to innovate.

Figure 4. 14 Mtavu location as surrounded by mountains

4.7.1 Farmer 2WMM

Farmer 2WMM was born in 1959 in a poor subsistence family. His family was relocated from their land when the government expanded the Chikangawa Plantation (Viphya mountains) in 1970s. Because of this, they had to relocate to the west of the forest where their friends gave them land to settle and farm. His household has four members because the other children moved out because of marriage. He owns over five hectares of land which he inherited from his father and has since given some of it to his male children and for the establishment of a new school. Currently, the school he helped establish wants him to move off his own land, a battle he fights every year. Through his hard working, he managed to improve his livelihoods by investing in livestock (cattle, goats, chickens and pigs) which multiplied well. He also started a small grocery shop which was an important source of school fees for his children. He does not hold influential positions in the community. According to him, most of his colleagues now discriminate against him because of his achievements.

Figure 4.15 Maize stalks on 2WMM's DBF plot at the foot of a mountain.

His DBF plot conforms to almost all Tiyeni requirements. For example, beds showed to be around 30cm in depth, surfaces had been covered by crop residues, contour ridges had vetiver grass, box ridges were well spaced with closed ends (Figure 4.19). In terms of manure, he applies raw cattle manure given that he has more than he can use. He has since expanded his DBF plot size because of the technology's ability to contain rainwater.

4.7.2 Farmer 2KMM

Farmer 2KMM worked for Tobacco Auction Floors, a tobacco marketing company in Lilongwe until an accident that made him redundant in 2003 which forced him to return home in 2004. His family gave him land upon his return, but the soil was infertile. With knowledge gained in Lilongwe, he began crop residue retention, composting and other techniques which reclaimed the soil’s fertility to become one of the most productive plots in the area. Since his return, his main livelihood activities have been rainfed agriculture, livestock, wetland cultivation and bricklaying.

Figure 4.16 Free roaming pigs feeding on maize stalks in Mtavu.

His DBF plot is located on a slightly steep land with brown soils with high iron contents. His deep beds are well around 30cm depth, with box ridges and contour ridges planted with cassava. The plot is near houses with roaming livestock which destroy crop residues on bed surfaces before they can decompose (Figure 4.20). Coupled with trampling by animal hooves, bed surfaces appeared hardened, compacted, and desiccated.

4.8 Chapter summary

Beginning from district characteristics to study areas and individual farmers (key informants), this chapter has described the social-ecological settings under which this study takes place. Noted are the striking differences between study sites located in Nkhata Bay district from those in Mzimba in terms of topography, soil types, rainfall patterns, their proximity to the nearest urban areas (small towns or Mzuzu city) and crop preferences. Uniqueness of place is also noted from one study site to the next even in the same districts. At farmer level, socio-economic characteristics have been provided. Most importantly, differences in terms of how farmers practise the DBF have been highlighted. Chiefly, emphasis on which DBF components are practised has been emphasised. This chapter is essential for this study because the proceeding chapters draw on these site-specific characteristics to explain key findings. Singularly, Chapter 9 relies on these site-specific social-ecological settings to model various scenarios that arise from key findings in Chapters 5 to 8.

Chapter 5

The Ecological Impacts of the Deep Bed Farming System

Chapter overview

This chapter explores the ecological impacts of the deep bed farming (DBF) system by focusing on soil fertility, soil erosion quantification and maize yields. It presents the statistical results for paired independent DBF and CR soil samples which were analysed for organic matter (OM), organic carbon (OC), nitrogen (N), phosphorus (P), bulk density (BD), electrical conductivity (EC) and pH for the two- and five-year old plots. The last section of this chapter triangulates these results by incorporating farmers' lived experiences of the DBF relating to these variables. The first two sections are designed to help compare scientific reality with farmer experiences. The third section explores the relationships among these variables to help understand the contributions of each of these variables into the variance observed.

5.1 Analysis of soil variables

Soil samples, soil erosion monitoring and maize yields from 24 plots comprising 12 DBF and 12 CR form the core themes of this chapter. These plots are located across three two-year sites (Mtavu, Kapata and Thandazga) and three five-year sites (Chikwina, Chipapa and Jalanthowa) belonging to 12 volunteer farmers. Except where material replacement was required due to theft (Section 3.5), these plots were entirely managed by farmers. This chapter integrates quantitative findings with qualitative data from plot owners about their experiences and observations concerning ecological aspects of interest. Table 5.1 provides an initial summary of all variables measured and analysed under this chapter. Table 5.1 provides an initial summary of all variables measured and analysed under this chapter.

Sample characteristics

Running the Shapiro-Wilk’s normality test at p<0.05 (Razali & Wah, 2011; Shapiro & Wilk, 1965) and visual inspection of the resultant histograms, normal Q-Q and box plots on pH, EC, P, OC, OM, N, BD, water infiltration rates, maize yields and soil erosion quantity datasets showed that some of the datasets were not normally distributed. For consistency, the non-parametric Mann-Whitney U Test was applied to test for significant differences between DBF and CR soil variable means. Table 5.2 provides a summary of the results of the analysis.

Table 5.1 Summary of 2- and 5-year DBF and CR soil variables and maize yields (n=48)

Variables		**Number of years**			
		2 years		**5 years**	
		Mean	Standard Deviation	Mean	Standard Deviation
Electric conductivity (dS/m)	CR	11	6	9	3
	DBF	15	7	12	5
pH measured in water	CR	5.78	.80	5.70	.37
	DBF	5.78	.60	5.58	.47
Phosphorus (ug/g)	CR	26.04	19.18	22.42	17.08
	DBF	29.45	18.58	31.47	17.31
% Organic Carbon	CR	.39	.23	.56	.22
	DBF	.61	.27	.59	.28
% Organic Matter	CR	.68	.39	1.02	.44
	DBF	1.05	.47	1.02	.49
% Nitrogen	CR	.03	.02	.05	.03
	DBF	.05	.02	.05	.02
Bulk density	CR	.64	.67	.68	.71
	DBF	.64	.68	.67	.70
Soil erosion (kg/40s.m.)	CR	12.67	14.80	17.00	24.17
	DBF	6.50	8.20	8.50	11.18
Infiltration rate (ml/s)	CR	1.40	2.21	2.08	2.93
	DBF	2.89	4.04	2.83	3.75
Maize yields (kg/40s.m.)	CR	9.68	13.89	7.83	9.61
	DBF	14.43	19.78	9.63	10.68

Table 5.2 Differences between DBF and CR using Mann-Whitney U Test at p<.05. (n=24)

Variable	Z-score	Sig. (p<.05)	Mean	
pH	-0.216	0.825	DBF	5.68
			CR	5.74
EC	2.226	**0.025**	DBF	13.70
			CR	9.83
P	1.453	0.147	DBF	31.21
			CR	24.25
OC	1.34	0.18	DBF	0.61
			CR	0.50
OM	1.185	0.234	DBF	1.03
			CR	0.86
N	1.453	0.147	DBF	0.05
			CR	0.04
Bulk density	-0.202	0.841	DBF	1.30
			CR	1.31
Infiltration rate	1.501	0.133	DBF	5.7
			CR	3.4
Maize yields	1.096	0.271	DBF	25.7
			CR	21.3
Soil erosion	-2.626	**0.008**	DBF	15.0
			CR	29.6

5.1.1 Soil pH

Given that one salient feature of the DBF is the making and application of organic manure, it was expected that pH levels would be significantly different between the two farming systems. A comparison of pH between DBF and CR plots did not indicate significant differences between the two farming systems (p=0.825) (Table 5.2) except on 5GN’s plot in Chipapa (Figure 5.1). The optimal soil pH range for the growth of maize (*Zea mays L.*) is reportedly 6.1 to 7.3 (neutral or near neutral pH) (The et al., 2006). According to Brewbaker, (1985) and Granados et al. (1993), tropical African soils are slight to acidic. According to Shukla et al. (2004), pH is normally unresponsive to tillage practices over a small hectarage besides being influenced by parent material. All DBF plots under the study were smaller than a quarter of an acre such that DBF interventions could not amount to any significant changes across all sites. Lastly, the lack of differences in pH of soils under DBF is indicative of the lack of or insufficient organic manure application on beds. Nziguheba et al. (2000) and The et al. (2006) found that organic manure corrected soil acidity to neutral or near neutral.

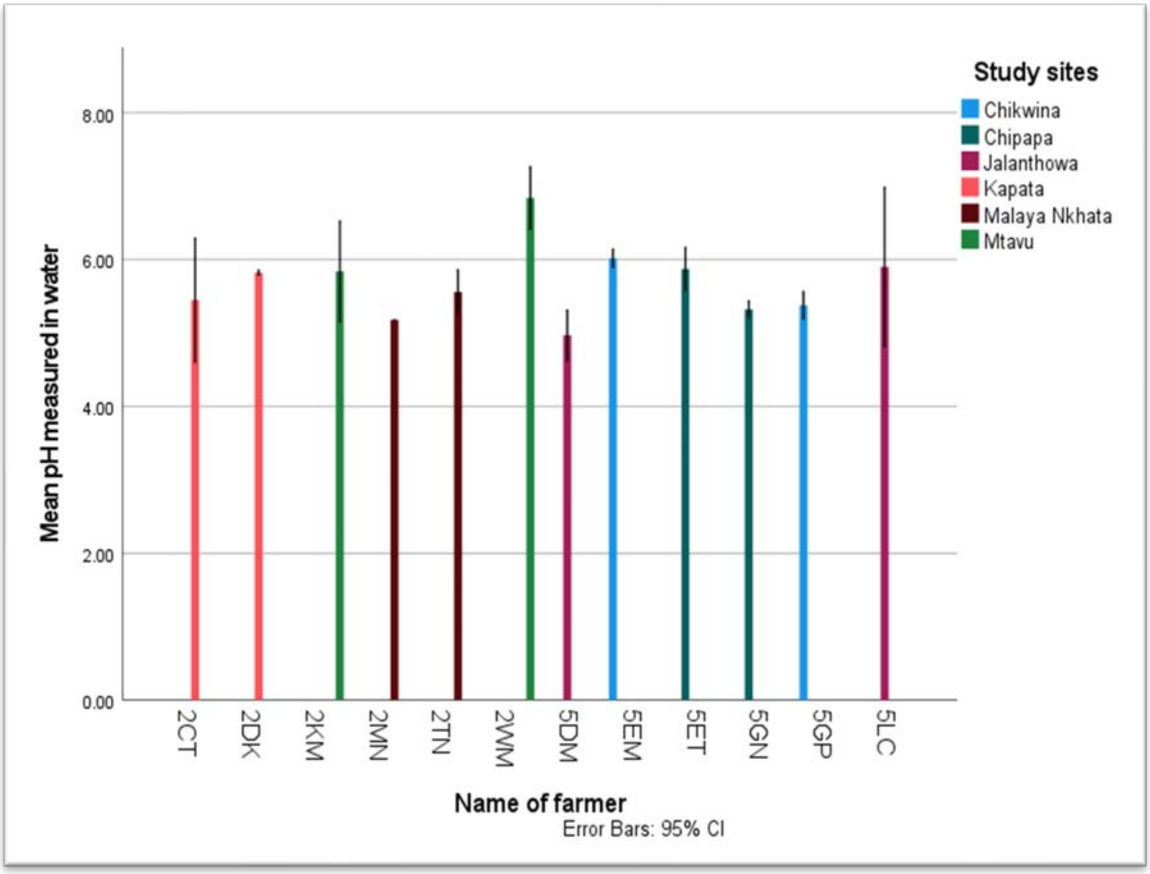


Figure 5. 1 Comparing pH levels in DBF plots across sites (DBF only, n=12)

5.1.2 Electrical conductivity (EC)

Soil salt quantity measured as EC between DBF and CR plots showed significant difference (p=0.025) (Table 5.2). Soils under DBF across two and five-year-old plots showed higher readings of EC with means of 15mS/m and 12mS/m respectively against 11mS/m and 9mS/m in CR (Figures 5.2 and 5.3). Maize does well in soils with salt contents between 0-18mS/m (Abrol et al., 1988; Mloza-Banda et al., 2016). Despite being statistically different, both DBF and CR plots remain within the optimal ranges of soil salt contents. Soils with high contents of organic matter (humus), small particle sizes (texture) and high porosity have high capacity to retain positively charged ions that increases EC readings (Visconti & de Paz, 2016). The application of organic manure and deep tillage that loosens and breaks large soil clumps in DBF may explain why soil under DBF is found to have high EC than the adjacent soil under CR.

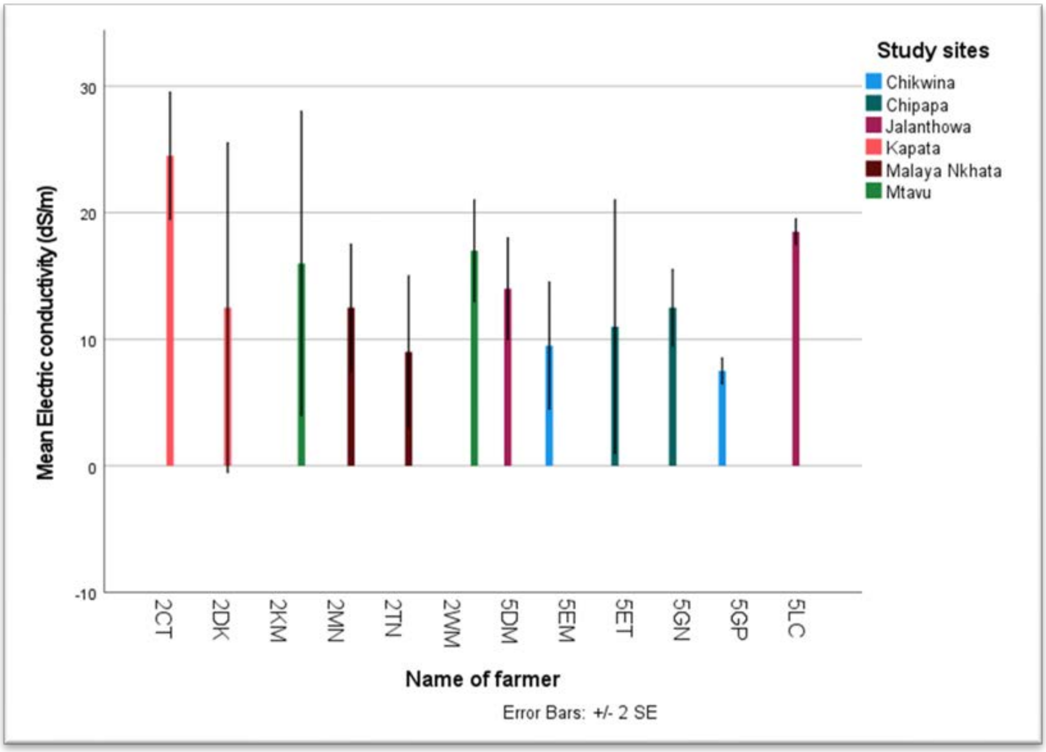


Figure 5. 2 Comparing pH levels in DBF plots across sites (DBF plots only) (n=12)

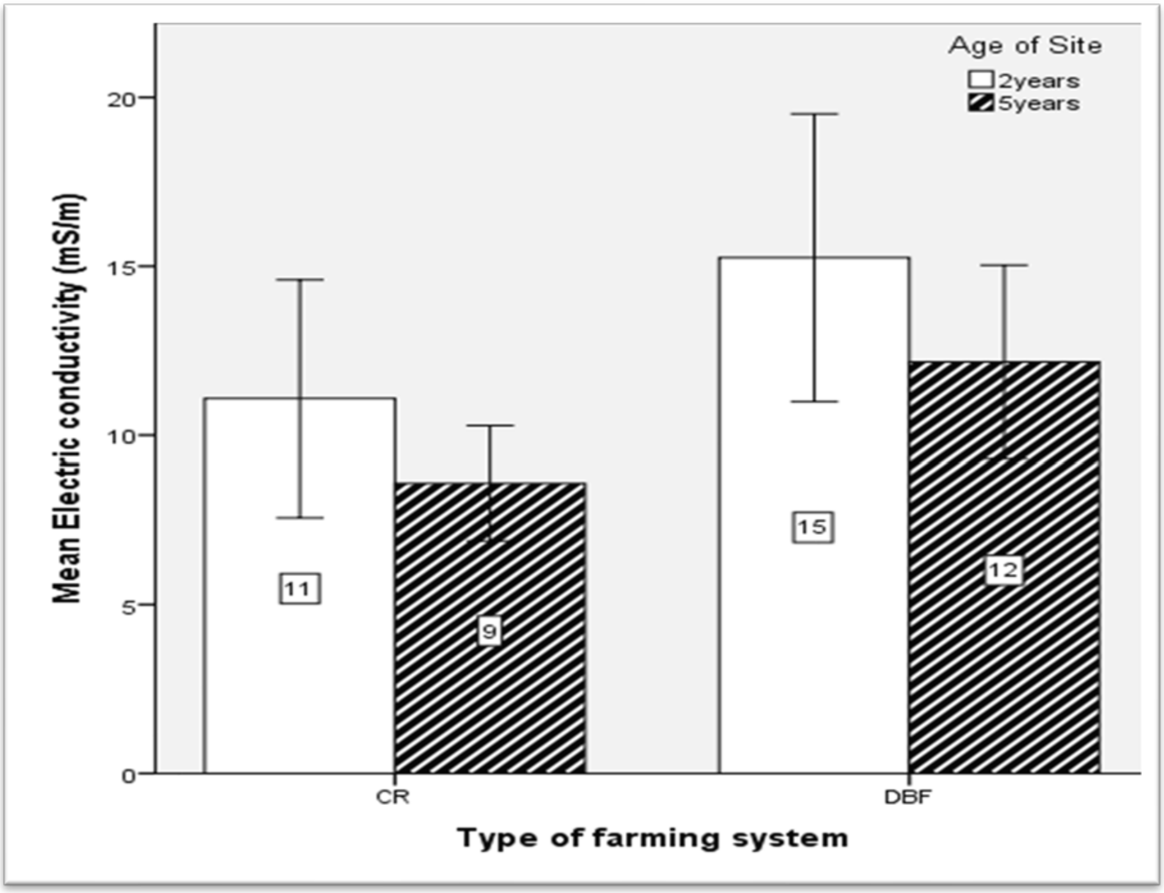


Figure 5.3 Mean EC in DBF and CR plots.

5.1.3 Phosphorus, soil organic carbon, and organic matter

No significant differences were found between DBF and CR in terms of phosphorus (P) levels (Table 5.2). Despite not being significantly different, both two- and five-year DBF plots tended to give higher levels of phosphorus given that 75% of all P levels were above 20ug/g than CR plots (near or below 15ug/g). Similar findings have been reported by Mloza-Banda et al. (2016) and Njoloma et al. (2016) in contiguous CA and CR plots while also recognising that Malawian soils are normally higher in phosphorus levels (Sillanpaa, 1982; Snapp, 1998). Earlier studies such as Snapp (1998) suggested that P levels of >15ug/g (15 micrograms/gram) are optimal for crop cultivation. Both CR and DBF are near or above this critical value, suggesting that soils are inherently sufficient in phosphorus regardless of tillage types. Figure 5.4 shows large variability of P levels across both farming systems and two- and five-year plots, signalling the various levels of land management and crop husbandry practices including quantities of both inorganic and organic fertilizers applied. Variations also exist in DBF plots across study sites (Figure 5.5).

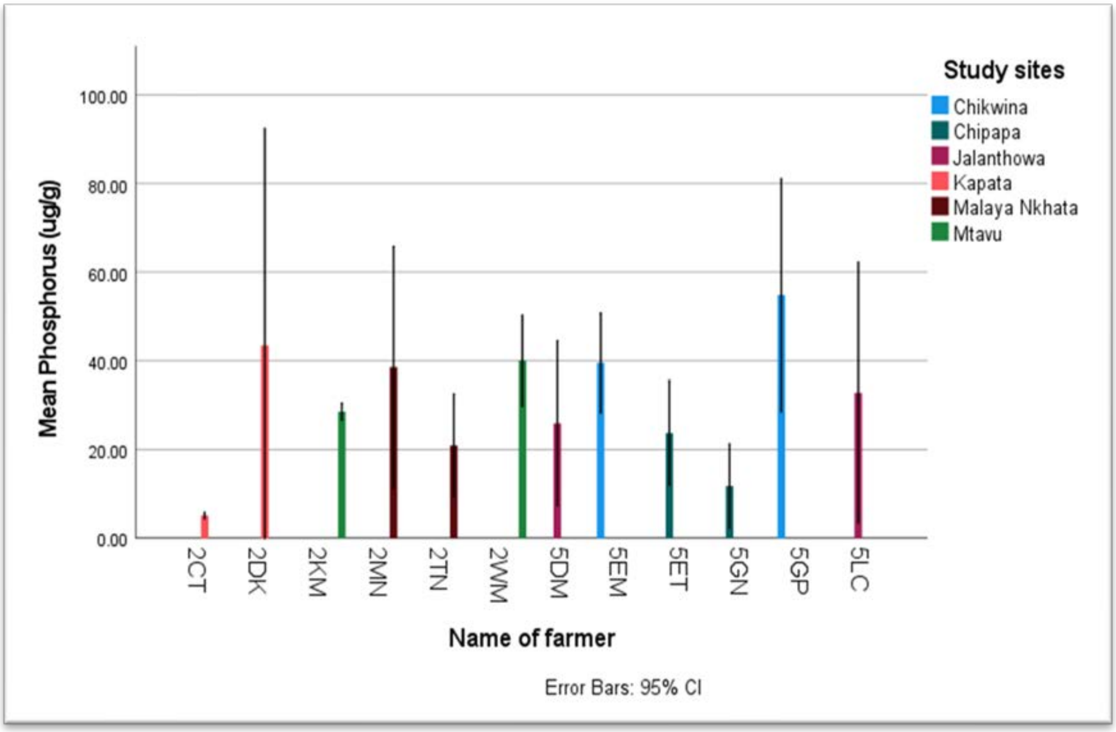


Figure 5. 4 Phosphorus levels across DBF plots (n=12)

Table 5.3 Comparison of soil variables in two and five-year DBF and CR plots.

Variable	**DBF$_{2yr}$ – CR$_{2yr}$**	**DBF$_{5yr}$ – CR$_{5yr}$**	**DBF$_{2yr-5yr}$**	**CR$_{2yr-5yr}$**	**DBF$_{2yr}$ - CR$_{5yr}$**	**2yr – 5yr**
pH	.794	.453	.509	.703	.904	.797
EC	.141	.078	.312	.238	.013	.123
P	.522	.118	.689	.703	.471	.893
OC	**.043**	.952	.976	.173	.904	.522
OM	**.043**	.952	.841	.173	.904	.433
N	**.040**	.888	.748	.204	.689	.421
BD	.631	.337	.631	.337	.337	.651
Infiltration rate	.378	.262	.936	.471	.471	.843
Maize yields	.575	.054	**.045**	.200	**.030**	.692
Eroded soil	.065	.065	**.020**	1.00	**.020**	.774

Similarly, no significant differences were found between DBF and CR relating to quantities of OC, OM and N (p= 0.18, 0.234 and 0.147 respectively) (Table 5.1). However, DBF plots showed higher levels of OC and OM in two-year-old plots than the adjacent CR plots (Table 5.3) while N levels remained constantly low across farming systems and two- and five-year plots. Results also show that these variables remain relatively constant in DBF between two and five-year-old plots while five-year-old CR plots register more OC and OM than two-year-old CR plots (Table 5.3 and Figures 5.3 and 5.4). Similarly, variations within the DBF category across plots and study sites are noted (Figures 5.7, 5.9 and 5.10), suggesting differences in crop residue retention and manure application levels and consistency.

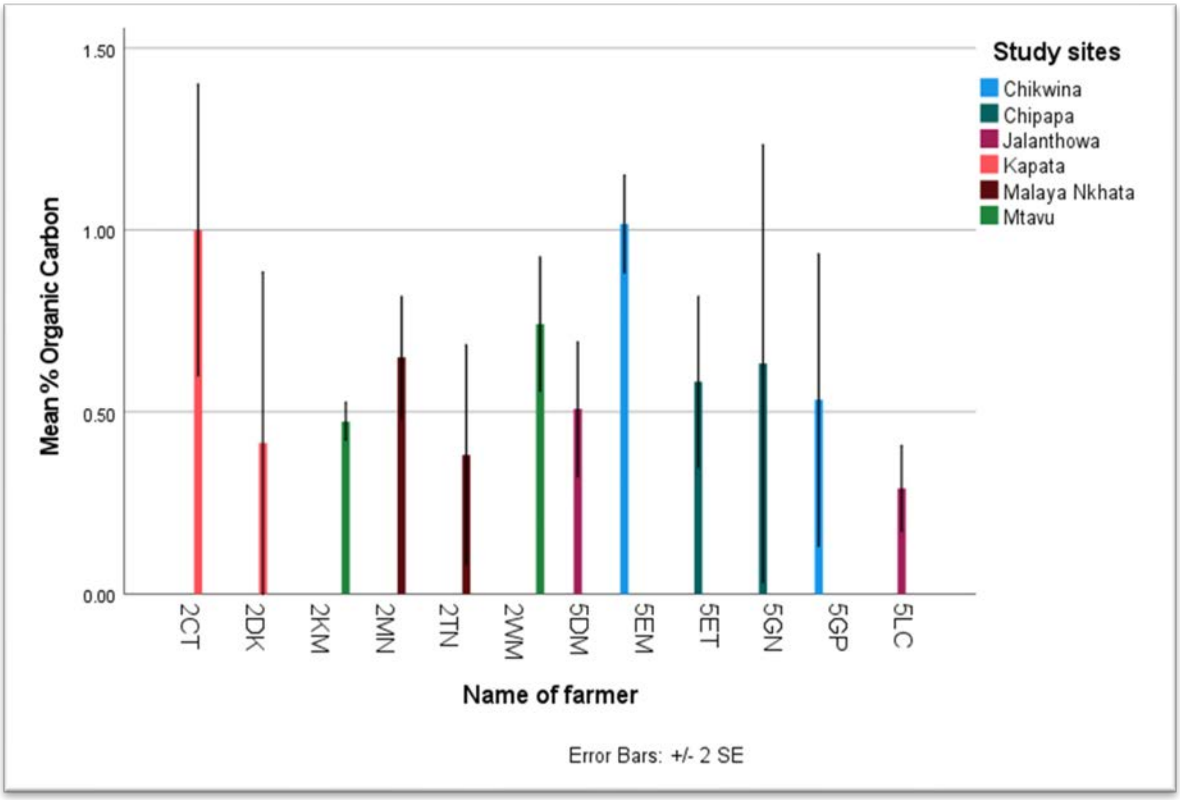


Figure 5. 5 Distribution of OC across DBF plots (n=12)

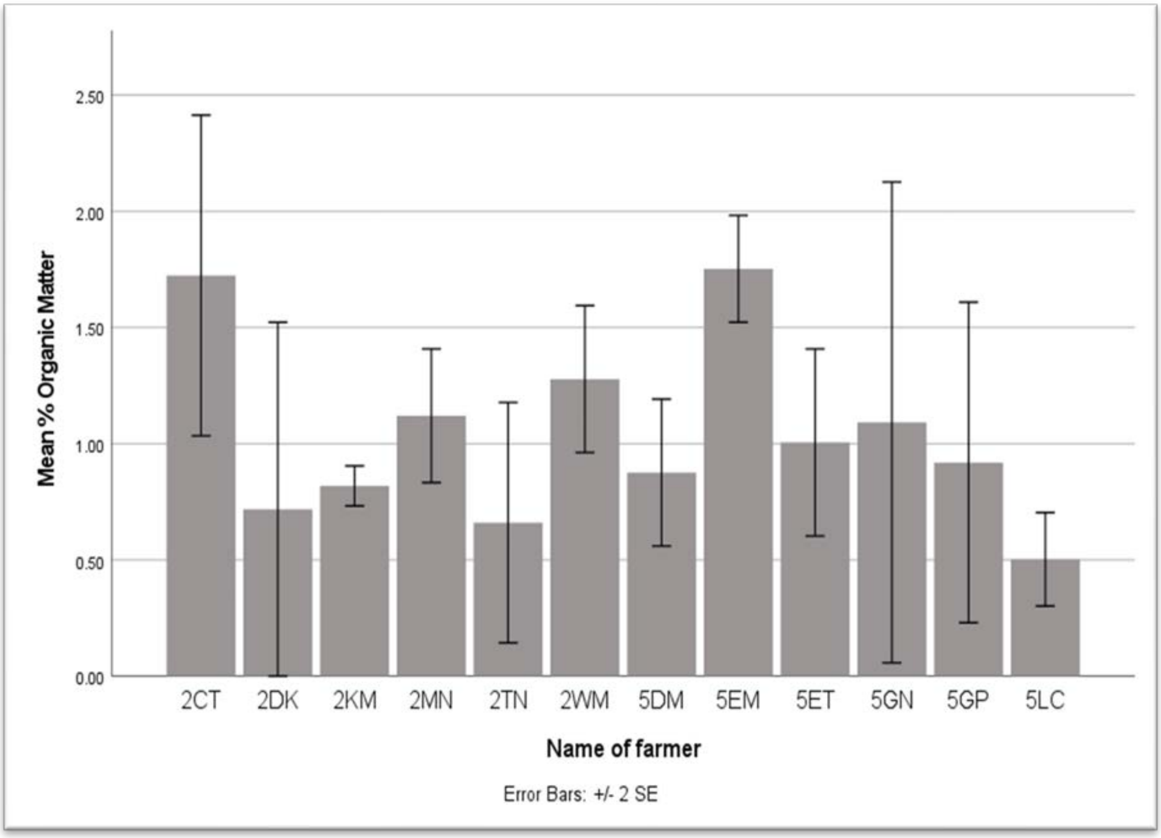


Figure 5.6 Organic matter across DBF plots (n=12)

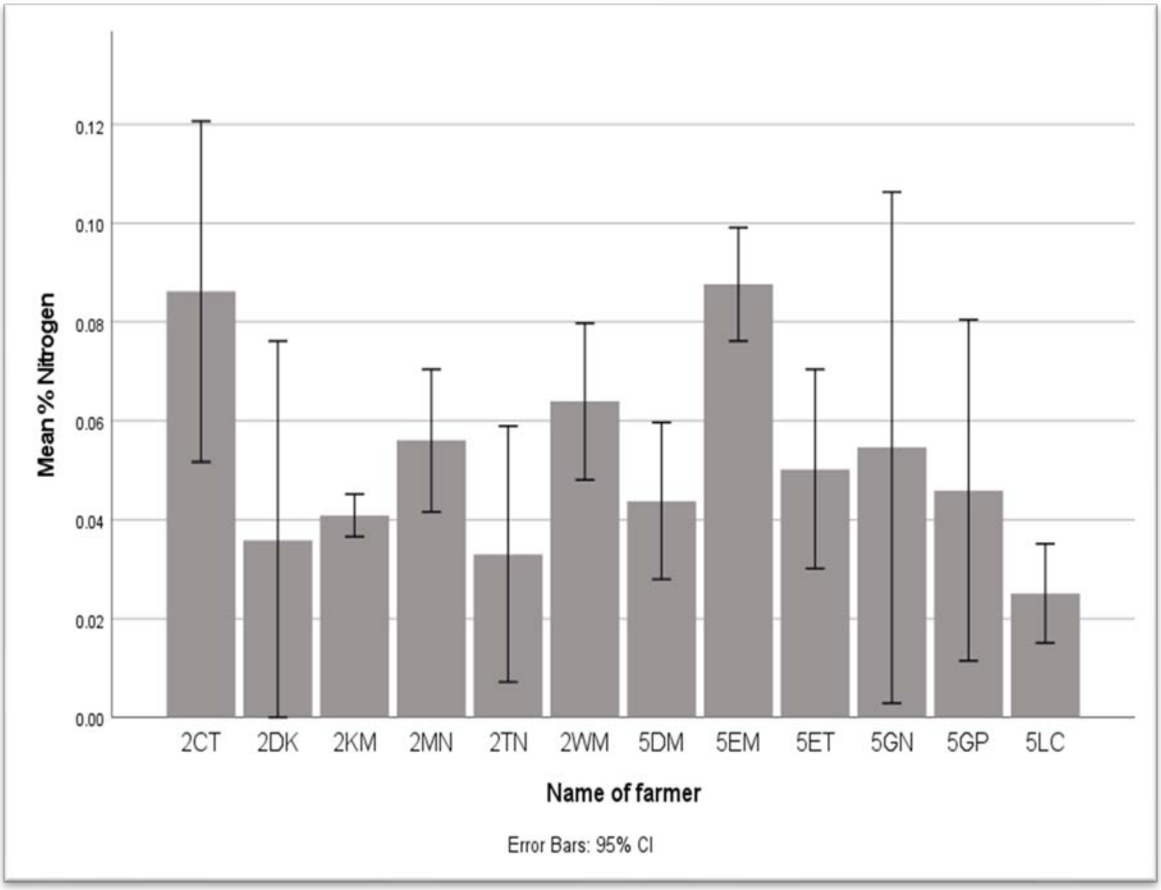


Figure 5.7 Nitrogen levels across DBF (n=12)

Soils with at least 0.8% OC and 2% OM are classified as suitable for the cultivation of maize and other commonly grown crops in Malawi (Snapp, 1998; Njoloma et al., 2016). In both farming systems and across two and five-year-old plots, OC and OM levels are lower that these critical values, but DBF plots showed the most variations. While CR practice is almost similar among all farmers in Malawi (Chibwana et al., 2012), DBF practice varies across communities and individuals granted its novelty hence such variations in OC and OM levels in DBF plots. OC and OM are critical in sustainable soil ecosystems as they provide energy for microbial activities and as adhesives like glomarin to bind soil particles together (Flaig et al., 1977; Habte, 2006; Montgomery, 2007; Shaxson et al., 2014).

Ngwira et al. (2012) and Mloza-Banda et al. (2016) found that implementing no-till CA significantly increased N, OC and OM reserves relative to adjacent CR plots. In their explanation, they suggested that this change is probably due to two factors: first, lack of tillage that halted rapid oxidation of organic carbon stocks and decomposition of organic matter, a key source of OC and component of soil's structural strength: secondly, consistent retention of crop residues which, in the long run, replenishes the lost OC and OM. The low levels of OC, OM and N in this study could be because of continued oxidation of carbon and SOM reserves due to deep tillage and subsequent bed maintenance without crop residue retention (Section 4.2).

According to Hudson (1981), Reicosky (2001), Habte (2006), Montgomery (2007) and Shaxson et al. (2014) tillage type, depth, frequency, and severity have the destructive consequences on soil porosity, oxidation of organic matter, pulverisation of soils, compaction and loss of the soil's structural stability to withstand direct impacts of raindrops. Consequently, these result in a destabilised soil's biochemical and physical equilibrium, unless crop residue retention, agroforestry and manure application are simultaneously done. From Chapter 4, most farmers do deep tillage without retaining crop residues and manure, a common challenge for CA practices in SSA (Erenstein, 2002; Vanlauwe et al., 2014; Cheesman et al., 2016). Such changes in these variables, therefore, are influenced more by variations in DBF practices among farmers than the physical characteristics of these places.

5.1.4 Soil bulk density (BD)

Bulk density between DBF and CR plots was statistically insignificant ($p=0.841$) (Tables 5.2 and 5.3) against the expectation of lower BD in DBF plots because of deep tillage. Figures 5.11 further show little variability of BD in both two and five-year-old DBF and CR plots with a mean of 1.30mg/m^3 in DBF and 1.31mg/m^3 (Table 5.2). Typical BD values in Malawi have been reported to vary between 1.41 to 1.50mg/m^3 between 0-30cm depth (Douglas et al., 1999) with variations dependent on soil type where sandy soils fall between 1.3 and 1.7mg/m^3 and 1.1 to 1.6mg/m^3 for fine-textured soils (Njoloma et al., 2016). Values greater than 1.6mg/m^3 have been found to restrict growth of crop roots, reduce soil porosity, consequently result in poor rainwater infiltration and increased runoff volume and soil erosion (McKenzie et al., 2004; Shaxson et al., 2014; Njoloma et al., 2016). Despite five-year-old DBF plots showing wide variations, both DBF and CR BD scores fall below 1.6mg/m^3 (Table 5.1 and Figure 5.11).

According to Gondwe (2019), crop residue retention is important for managing de-compacted soil layers on a DBF plot. The lack of soil cover on most farmer plots (Chapter 4) coupled with bed trampling by people and roaming livestock may result in rapid re-compaction of the seed beds due to desiccation due to direct sunlight and raindrop impacts. This explains why BD does not significantly improve under DBF. Rapid oxidation of OM without crop residue retention may exacerbate this problem given loss of OM results in collapsing of soil pore spaces as particle adhesives are lost (Reicosky, 2001; Shaxson et al., 2014). Furthermore, variations observed in five-year DBF plots could be indicative of reduced levels of DBF maintenance and care after three years when Tiyeni stops providing its support. The individual farmers' commitment to continuing bed maintenance, crop residue retention, or organic manure incorporation determines the extent to which each farmer can keep their soils de-compacted. Labour allocation trade-offs may also be a significant on whether continue practising any one of DBF components or not.

5.1.5 Water infiltration rates

Infiltration tests did not show statistically significant differences between DBF and CR with a p = 0.133 and overall means of 5.7 and 3.4ml/s respectively (Table 5.2). Similarly, a test for significance between two-year DBF and CR, and five-year DBF and CR plots did not show significant differences (p= 0.378 and 0.262 respectively) (Table 5.3) as did the comparison between two- and five-year DBF (p=0.936) two, five year and CR plots (p=0.471), two-year DBF and five-year CR (p= 0.471) and the overall two- and five-year plots combined (0.843). In both two- and five-year plots, DBF showed high rates of water infiltration rates relative to CR with means of 5.1ml/s and 6.2ml/s in two- and five-year DBF plots respectively. On the other hand, CR's two- and five-year plots had means of 2.5ml/s and 4.4ml/s respectively (Table 5.3). Further observations show that infiltration rates in DBF are almost uniform, with more variable values in CR (Figure 5.13). Like BD, these results may suggest rapid changes in soil physical structure, especially size and number of pore spaces from time of tillage to the end of the rainy season when measurements were taken. On the other hand, Figure 5.14 shows significant rainwater infiltration variations within DBF from one plot to the next. This is because of variations in the choices of which DBF aspects to practice and which ones not.

The results above suggest that DBF marginally improved water infiltration rates relative to CR in both two and five-year-old plots in all study sites except Malaya Nkhata where soils are largely sandy. On the other hand, farmer observations and experiences suggest substantial improvements. According to farmers, improved rainwater infiltration in DBF plots is made possible by some combination of soil de-compaction due to first-year 30cm deep tillage, large surface area of deep beds, application of organic manure, crop residue retention and box and marker ridges (Figure 5.14).

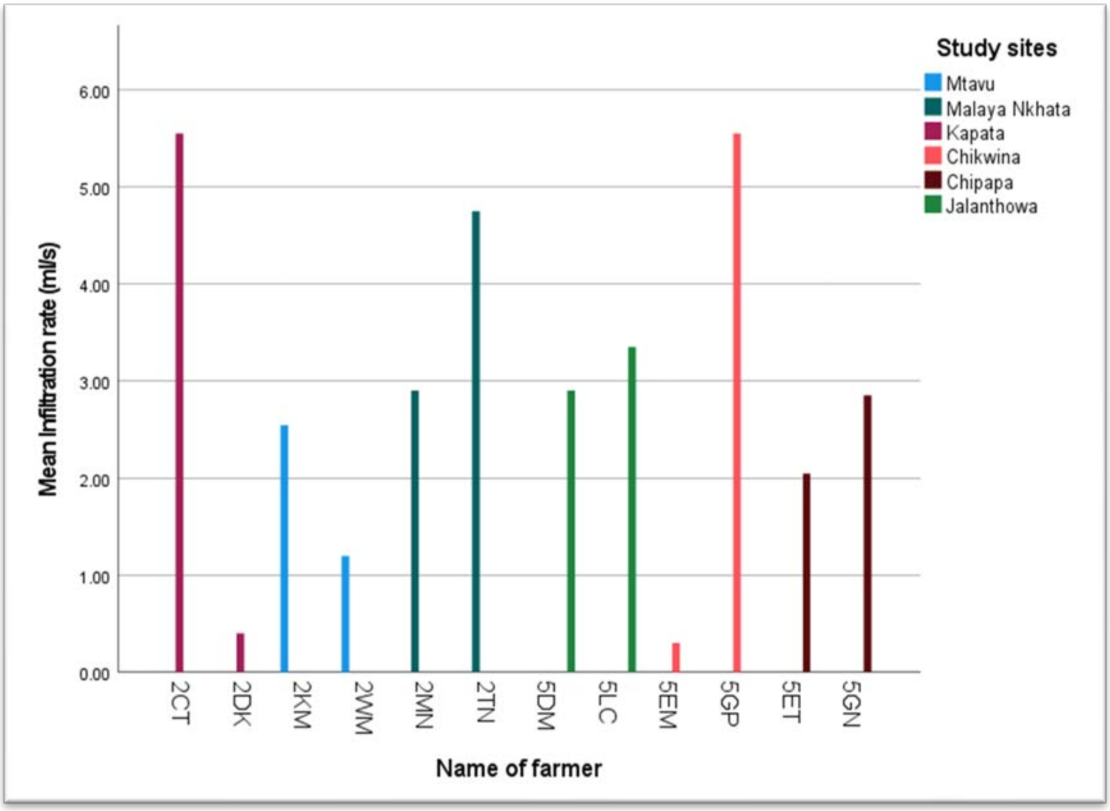


Figure 5.8 Rainwater infiltration rates under DBF (n=12)

Figure 5.9 Rainwater harvested in box ridges on a DBF plot (photo by G. Kumwenda).

Due to DBF's capacity to harvest and conserve rainwater (Figure 5.14), farmers have widely reported that crops grown on DBF are more likely to survive both droughts, dry spells, and destructive heavy rainfall events than those on ridges. Except for Chikwina and Malaya Nkhata, this is a significant contribution to resilience and sustainability of maize-based smallholder agriculture given its high vulnerability to climate variability and change impacts (Porter et al., 2014; Steward et al., 2018). While depending on drought resistant cassava as a staple crop, Chikwina is least affected by droughts or dry spells so these water harvesting, and infiltration benefits have the least significance. Similarly, Malaya Nkhata has sandy soils which allow rainwater infiltration without consistent crop residue retention, deep tillage, and box ridges thus such DBF benefits are insignificant. The extent of these benefits also depends on which DBF components a farmer chooses so variations are to be expected from farmer to farmer and across temporal and spatial scales.

> *"...together with deep tillage that loosen the compacted soils, manure, box and marker ridges help collect and sink the rainwater which would otherwise cause erosion. No matter how heavy it rains, all the water goes down the soil profile.*

> *This water is important for crop growth when there is a dry spell and also for recharging water sources for our dimbas.”*
>
> Farmer 2KMM, (2019)

> *“… Water is trapped in box ridges while the plot remains closed. This makes sure that the water goes does not go outside the plot. The tilled soil made into substantive 1m wide beds makes it easy for a large volume of rainwater to infiltrate compared to compacted small ridges. This why maize on DBF do not wilt like on ridges when there is a dry spell …”*
>
> Farmer 4MPJ, (2019)

5.1.6 Soil erosion

Mean soil erosion quantities in DBF and CR plots suggest the introduction of DBF significantly reduced the quantities of soil eroded by half compared to the amount in CR (Tables 5.1 and 5.2) (p= 0.008). Similarly, comparisons between two and five-year DBF plots showed a significant increase in soil erosion quantities in five-year DBF plots than in two-year olds (p = 0.020) and between two-year DBF and five-year CR plots (p =0.020) (Table 5.3). No significant differences were found when two- and five-year CR plots were compared (p = 1.0) as did the comparison between an aggregate of all two-year and five-year plots (p =0 .774). The amount of eroded soils in DBF were consistently lower than in CR in all study sites (Figures 5.15) as is the case when two- and five-year plots are compared (Figure 4.16).

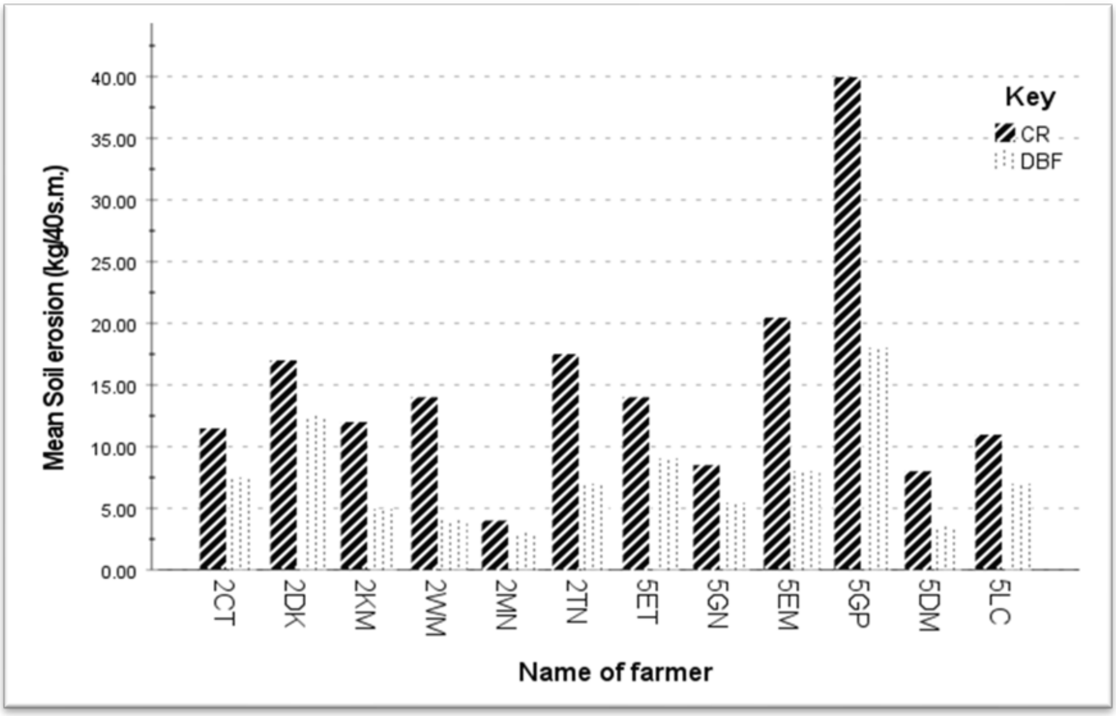


Figure 5.10 Soil erosion in two- and five-year DBF and CR plots (prefixed by 2 and 5).

Whereas all study sites showed varied extent of soil erosion in both DBF and CR, Chikwina and Malaya Nkhata represented two opposite ends of a continuum. Whilst Chikwina recorded highest of 20 t/h in CR 9t/h in the adjacent DBF plot, Malaya Nkhata had the lowest soil erosion of 2 t/h and 1.5 t/h in CR and DBF, respectively. Granted Chikwina's steep slopes and erosion-prone soils and Malaya Nkhata's flat terrain and high sand contents, variations observed are less about variations in DBF practices and more about these environmental features. Despite being on sloping land, for instance, 2CT's DBF plot in Kapata registered low erosion due to the plot's closed edges, contour and box ridges, crop residue retention, manure application and deeper beds than most plots, a similar case observed on 2WM's plot in Mtavu (Chapter 4).

The need for marker and box ridges in Malaya Nkhata, Jalanthowa and Chipapa is not as urgent as in Chikwina, Kapata and Mtavu. While water harvesting and reduction in erosion are important in Jalanthowa and Chipapa due to significant shifts in rainfall patterns, uptake of these aspects of the DBF depend on whether a farmer sees value in practising them. With steep slopes in Chikwina, Kapata and slightly in Mtavu, the same DBF features are key to solving the soil erosion problem. Conversely, functions of these

DBF physical features are accomplished by the flat terrain and sandy soils in Malaya Nkhata.

> *"…my land is largely made of sands as the rest of our community here in Chamalaza. I have never found water in both ridges and bed plots after any rainfall event. All I find are markings that show there was water. I do not think I have a soil erosion problem in my field, even when ridges are used…"*
>
> Farmer 6MNM, (2019)

> *"In beds, it may rain from 6 am to 6pm but the beds you will never see water on bed surfaces or signs of erosion because the tilled deep bed absorbs it all. It's like deep beds are always hungry for more water. But you also need to put maize stalks on top of beds to protect them from the sun. The bed surfaces can become sealed like cement floor when left unprotected."*
>
> Farmer 2KMM, (2019)

Field observations and interviews revealed that only farmers who recognised soil erosion challenges on their farms dedicated their time and effort in making marker and box ridges including making sure that plot edges are closed. For farmers, whose priorities are not reducing soil erosion or improving soil fertility, deep tillage, marker and box ridges, manure-making and crop residue retention activities become extraneous.

> *"…I have never seen that rainwater crosses over or breaks down deep beds as is often the case in ridges here in Kapata. The 2018-2019 rainy season had heavy rainfall events. I was surprised to see that no beds were broken by rainwater as compared to the adjacent ridge-based plot. All I found in my deep bed plot were water level marks. This means water goes into the soil profile, right?"*
>
> Farmer 5ANK, (2019)

Earlier studies in Malawi indicate that soil erosion is generally high in northern region (0.4 to over 39t/h/year) (Nakhumwa, 2004; Vargas & Omuto, 2014). Giller et al. (2009) and Andersson and D'Souza (2014) have previously argued that areas like these require more than reduced tillage and crop residue retention to halt soil erosion. The DBF provides some of these physical aspects that provide physical barriers to control rainwater in addition to deep tillage. A consistent practice of the combination of DBF's physical features, organic manure application and crop residue retention has the potential to further reduce soil erosion and halt soil degradation in the region.

5.1.7 Maize yields

While no significant differences were found between DBF and CR overall (p=0.271), maize yields were statistically significant between two-year DBF and five-year CR (P=0.030) and between two and five-year DBF plots (p=0.045) (Table 5.3). Similarly, a p value of 0.054 in the case of five-year DBF and CR plots denotes differences in maize yields between the two farming systems. On the other hand, there were no statistically significant differences between maize yields observed in two-year DBF and CR (p=0.378) and between five-year DBF and CR plots (p=0.378). Conversely, yield reductions have been reported in DBF by farmers who delayed or neglected crop residue retention and manure, late planting of crops, absence of box and marker ridges or insufficient deep tillage where they were necessary.

> *"…Since I started using beds, I have never seen good yields. Tiyeni promised to give us fertilisers, which they never fulfilled. I had to use my own seeds and fertilisers on their DBF plot, which is not how things work. The seeds and fertilizers I bought were meant for ridges and not beds… I have decided to make ridges and grow tobacco on that DBF plot."*
>
> Farmer 5DKK, (2019)

High yields in DBF resonate with many farmers, especially those barely surviving. Such benefits also influence where farmers locate their DBF plots. In areas where soils have been degraded due to overuse and erosion like in Jalanthowa, Chipapa and Mtavu, DBF is allocated to a section of land with poorer soils in the belief that the practice would improve soil fertility, halt soil erosion and de-compact soil hardpans and eventually improve maize yields. Plant spacing, according to farmers, also contributes to the high maize yields in DBF. According to farmers' observations, the 25cm spacing between planting stations makes sure that a plot has optimal plant population unlike in CR. Other farmers have cited manure as being important factors that improve maize yields in DBF in combination with a looser soil profile, water harvesting and conservation functions therein.

> **“***…I had a plot with very poor soils due to erosion. Maize yields had always been poor since 10 years ago and so I decided to have deep beds on that land. Now this plot is my best plot. It’s where I get highest yields, despite it’s small in size. Apart from manure and deep tillage, these beds have helped to keep the moisture on that plot and also reduced erosion. The measurement in beds are precise, increasing crop count on a small plot relative to CR...”*
>
> Farmer 4RMJ, (2019)

> *“Bed dimensions and plant spacing are precise in DBF than our traditional ridges where more space that could be used for crops is wasted. This makes deep beds have more plant population per plot of the same size as that of ridges hence more crop yields in DBF than ridges.”*
>
> Farmer 4RMJ, (2019)

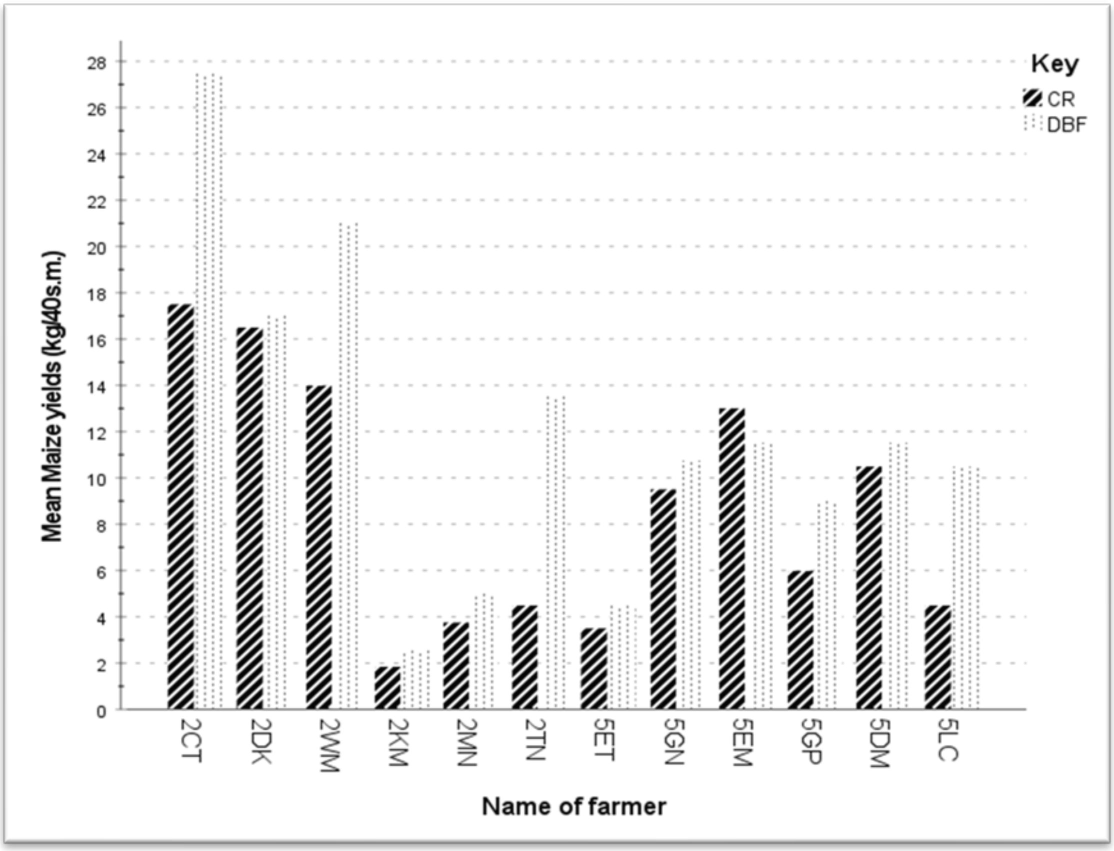


Figure 5.11 Maize yield differences in two and five-year DBF and CR plots (n=12)

Like infiltration results (Section 5.1.5), Figures 5.17 and 5.18 show declining trends in maize yields in five-year DBF plots relative to two-year old ones. According to Chambers (1994) and Cornwall and Jewkes (1995), farmers' enthusiasm in participating in a development project like agricultural promotion initiatives wanes over time. This is normally because of unfulfilled expectations like cessation of handouts, reduced contact frequency with extension staff or mismatches of outcomes versus advertised benefits (Andersson & D'Souza, 2014). As farmers' interest in participating in DBF activities declines, their dedication to and investment in the implementation of its components also potentially declines. Consequently, DBF's full potential is not realised, thus soil quality and maize yield improvements observed in early years gradually cease. Against that background, farmers with more than three years DBF experience are more likely to stop crop residue retention, organic manure application and yearly bed maintenance. By the passing of time, DBF plots return to the same state as those plots under conventional ridge-based cultivation with crusted and sealed soil surfaces, compacted soil layers and negligible organic matter additions into the soil ecosystem.

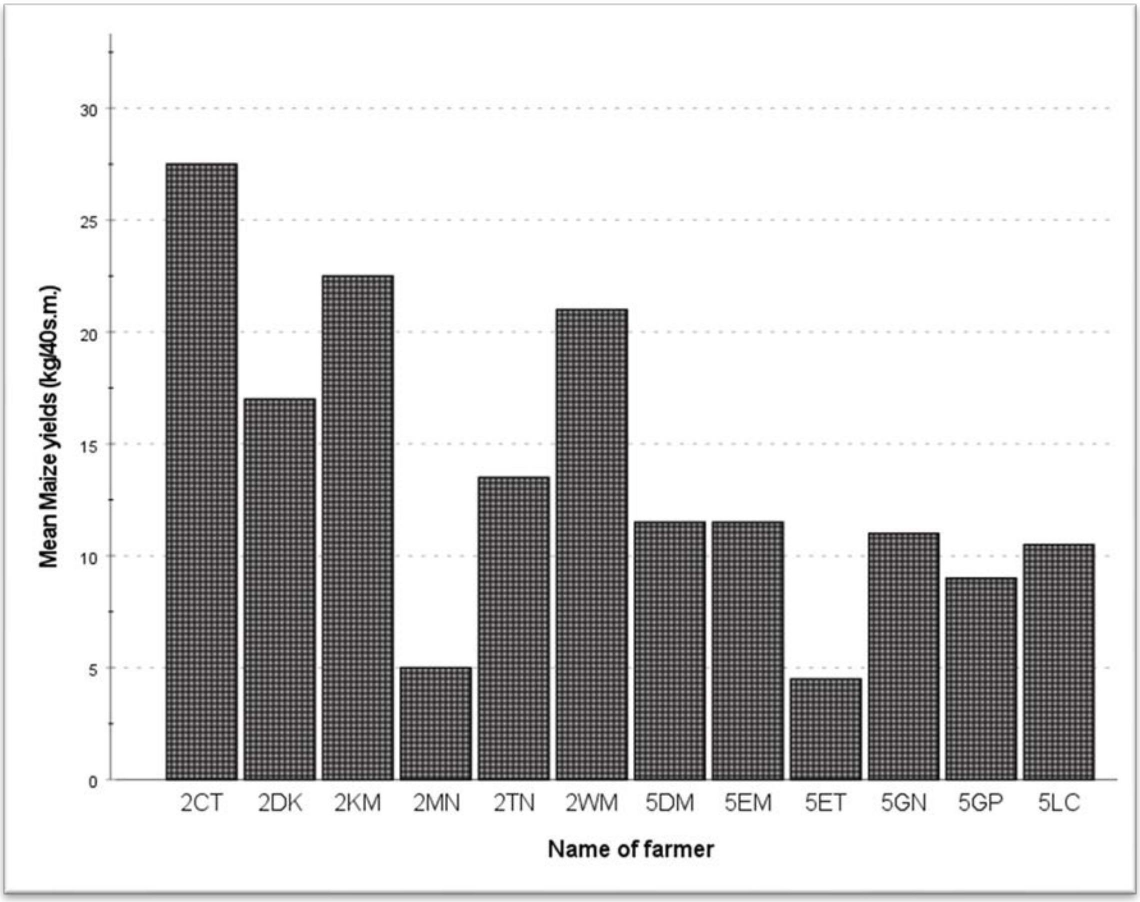


Figure 5.12 Maize yield quantities under two- and five-year DBF plots (n=12)

5.2. Farmers' perspectives of the DBF versus expert expectations

5.2.1 Deep tillage, marker, and box ridges

According to farmers, deep tillage de-compacts their compacted soils to create a sponge-like soil structure that can absorb and store rainwater and slowly release it when its most needed. Consequently, such conditions reduce soil erosion, improve crop rooting depth, reduce weed infestation, and helps mix fertile topsoil with sub soils while improving microbial activities where manure is applied, and crop residues retained on bed surfaces.

Width and depth of the beds also means that there is increased surface area for water absorption and storage on a DBF plot than on ridges. Given their large surface sizes, crop roots are prevented from being exposed to aggressive external conditions due to raindrop impacts as is the case on a CR plot with small ridges.

> *"…soil under DBF is better in many ways. The deep tillage ensures that the soils are well mixed while also breaking down the hard soil beneath the surface. This mixing helps to incorporate dead plants and small animals on top of the soil into the soil profile..."*
>
> Farmer 4LJJ, (2019)

> *"…deep beds are bigger than ridges in addition to being well tilled to absorb more water and to release it slowly for plant use. Crops on beds do not wilt when there is a dry spell. Also, maize roots are easily exposed to the sun and rainfall in ridges than on deep beds."*
>
> Farmer 4DMJ, (2019)

According to Tiyeni recommendations, farmers are supposed to plant vetiver grass on marker ridges for contour ridge re-enforcement. While Chikwina, Kapata and Mtavu farmers find this useful, those in flat locations observed that having contour and box ridges with closed plot edges effectively prevents soil erosion. For instance, Malaya Nkhata farmers with sandy soils find inclusion of deep tillage, box ridges, and vetiver grass unnecessary. On the other hand, farmers with the least land holding in sites like Jalanthowa, Chipapa and Mtavu may find the grass invasive given its ability to grow and spread its extensive root system beyond contour ridges hence reducing plot.

> *"…I plant cassava on beds instead of vetiver grass. I find it unwise to grow grasses when I can grow cassava that will give me food. My children come to get some cassava, unlike the grass. I have vetiver on one of the marker ridges for Tiyeni"*
>
> Farmer 2KMM, (2019)

> *"…I hate vetiver. It's the most difficult and useless grass. It has very stupid rooting system that can cover two metres around where you grow it in less than four years. Imagine you have this grass every ten metres in your plot! It may be too late to realise that the roots have covered half of your plot. My plot near the road is often visited by white people. I plant vetiver on that plot just to please them. I call it Chinyenga Wazungu (*translated as cheating white people*)"*
>
> Farmer 4DMJ, (2019)

5.2.2 Organic manure

Farmers who make and apply manure in their fields like Watchman Mvula Mtavu and Celina Thindwa in Kapata have observed higher maize yields and soil fertility improvements than inorganic fertilizer only. Similarly, farmers like Daniel Kondowe in Kapata and Martha Munthali in Chipapa attributed low maize yields in their DBF plots to their failure to make and apply manure. Indeed, field observations and maize yields substantiate their observations. For example, Section 5.1 reports high maize yields on 5CTK's DBF plot who applied manure for all years she practised the new system. In the same area, Daniel Kondowe observed no difference in crop productivity which he attributed to lack of manure besides poorly made beds. Other farmers have also observed that organic manure application significantly improves maize yields on CR even in areas with overused and degraded soils like Jalanthowa (see 4LJJ and 4DMJ's quotes below). The perception that one cannot practise DBF without manure also makes those without livestock fail to extend DBF plot size, scale it down, or abandon it entirely.

> *"I think what helps keep the moisture are two things; the manure I add in the beds and the crop residues I have been putting on top. In beds, moisture remains compared to ridges and maize does not wilt."*
>
> Farmer 4LJJ, (2019)

> *"I think you can also improve yields in ridges by applying manure. I have used this on my small plot and yields have been better. However, yield increases will not match DBF. Ridges are still compacted, shallow and erosion is still widespread"*

Farmer 4DMJ, (2019)

> *"The only challenge with DBF is that, if you don't make manure, then you will yield nothing. It can be discouraging for farmers who have no goats or pigs. Others are better off because they have cattle to give them manure. No manure, no Tiyeni farming."*
>
> Farmer 2KMM, (2019)

The organic manure in DBF system is a vital component for replenishing lost soil nutrients (Otsuka & Kalirajan, 2006; Zant, 2014). According to Shaxson et al. (2014), organic manure can also help to improve rainwater infiltration through its ability to improve soil microbial activities, reducing runoff volume and the risk of soil erosion in the process. These are core aspects of resilient and sustainable cropping systems that can survive ravaging ecological shocks and pressures (Schlenker & Lobell, 2010; Lobell et al., 2011; Cairns et al., 2013; Lobell et al., 2014; Niang et al., 2014; Steward et al., 2018).

5.2.3 Crop residue retention

The importance of crop residue retention (Figure 5.19) cannot be over emphasised. Even among farmers, ramifications of not retaining organic materials on bed surfaces have been widely acknowledged, including soil desiccation and surface sealing, and weed infestation where raw animal manure is applied. Indeed, most of bed maintenance needs that arise after a year of DBF practise is attributed to the lack of permanent organic cover that is common among first year DBF farmers (Figure 5.20) which could be prevented or reduced if crop residue retention starts right from the first year of implementation. Such realisations corroborate results in Section 5.1 where, despite deep tillage, physical parameters of soil under DBF did not show significant improvement.

> *"…farmers who did not lay maize stalks on the beds ended up with hard bed surfaces in the second year, requiring another tillage to make beds better. Without residues, manure application encourages the growth of weeds like duru (Eusine indica L.). Many of us are not used to laying maize stalks on our farms…"*
>
> John Mayuni Kalua, Kapata

> *“Many of us did not lay maize stalks on deep beds in the first year. They were all destroyed or used elsewhere by the time we realised beds needed them too. My plan was to start mulching in year two onwards…”*
>
> Farmer 4DMJ, (2019)

Figure 5.13 Maize stalks as mulch on 2WMM's DBF plot in Mtavu

Figure 5.14 Newly constructed beds without crop residues.

Despite its importance, this aspect of the DBF is least practised among smallholder farmers in all six study sites as is the case across the SSA (Erenstein, 2002; Giller et al., 2009; Andersson & D’Souza, 2014) due to a plethora of complex challenges. These include labour trade-offs on whether to engage in crop residue retention or off-farm livelihood activities, competing uses for maize stalks, negative experiences from previous encounters and an area’s weather phenomena. Maize stalks may be needed for construction of temporary shelters, source of liquid soda for preparing relish/food, preparation of tobacco nursery beds, or as raw materials for making manure. Still, other farmers, especially elderly women, burn them because ashes provide nutrients that crops like pumpkins require to grow well.

> *“I delayed mulching my no-till plot eight years ago because I was busy in the dimba. The result was disastrous. Maize stalks did not decompose and invited white grubs, large termites, worms and frogs. These began eating the germinating maize and beans. …Since then, mulching my fields is the last thing I will do.”*

Farmer 1GNC, (2019)

> *"Maize stalks have many uses so they are not enough sometimes. For example, I burn and soak their ashes in water to get liquid soda for cooking my delere (okra). When we have large church gatherings or weddings, men use the same stalks to construct shades for accommodation…"*

Farmer 1GNC, (2019)

> *"I normally burn maize stalks on my tobacco nursery beds to kill tobacco germs and diseases and to provide some nutrients for the seedlings. Surplus stalks are burn on-farm to reduce land clearing labour."*

Farmer 5DKK, (2019)

Prolonged rainfall events may lead to maize cobs rotting before they are ready for harvesting and result in substantial pre-harvest crop losses if a farmer takes no preventive measures. This problem may be worsened by presence of mice or termites which thrive in such damp conditions and begin to cut and dislodge maize stalks to the ground, further exposing them to moisture and warmth that trigger germination or decomposition. Such experiences force farmers to use different harvesting methods which in turn make it difficult to retain maize stalks or introduce uneven distribution and shortages. Use of conventional maize harvesting method where stalks are cut and stacked onto a large standing stook (Figure 5.21) is one common preventive intervention.

> *"When your plot is attacked by termites and mice before harvesting time, the priority is to save your food. A wise person would not worry about mulching at this time. Stooks help deal with that problem but makes it difficult to mulch because you have to carry maize stalks back to beds."*

Farmer 1KMC, (2019)

Figure 5.15 Harvesting maize on a stook for drying before harvesting in Kapata.

5.3 Relationships among DBF variables

To understand the relationships that exist among soil variables in DBF system, Principal Component Analysis (PCA) was undertaken. PCA is a form of cluster analysis which provides meaningful ways to visualise and differentiate between the most significant variables that account for major changes in a system.

5.3.1 Principal component analysis

The ten variables (nine soil variables and maize yield) were subjected to PCA with Varimax rotation (orthogonal) (Field, 2009; Starkweather, 2011) to reduce data points to interpretable size with the most factor loadings. The KMO measure (Kaiser-Meyer-Olkin) was used to verify the sampling adequacy for the use of PCA on the variables. The analysis yielded a KMO of 0.609, a measure significantly greater than the recommendation of >0.5 (Field, 2009). Moreover, Bartlett's test of sphericity x^2 was calculated as 559.00 with $p < .001$, indicating that correlations between variables were sufficient for running PCA.

The initial analysis was run to obtain eigenvalues and factor loadings for each component. Using Kaiser's criterion where only components with eigenvalues of ≥ 1 qualify for extraction from a dataset, the analysis yielded three principal components (PCs), which when combined, accounted for over 73.86% of the variance (Table 5.4). Examining the resultant scree plot (Appendix 3), however, presented some ambiguities as it showed two main inflexions that would suggest retaining four principal components. The structural matrix with variable loadings after Varimax rotation (Table 5.5) and a plot of rotated eigenvalues (Figure 5.25) supported the idea of retaining only three components (Table 5.5) for the interpretation of the results as they were the only ones with factor loadings of greater than 0.3 (Andrews & Carroll, 2001; Starkweather, 2011; Field, 2009) hence only three components were retained.

Table 5.4 PCA factor loading matrix (before rotation) for the three retained components.

Variables	Component		
	1	2	3
pH measured in water	-0.033	-0.140	0.629
Electric conductivity (dS/m)	0.079	-0.022	0.257
Phosphorus (ug/g)	-0.114	-0.008	0.528
% Organic Carbon	0.333	-0.019	-0.079
% Organic Matter	0.337	-0.035	-0.060
% Nitrogen	0.330	-0.046	-0.040
Bulk density	-0.047	0.330	0.021
Soil erosion (kg/40s.m.)	-0.068	0.300	-0.021
Infiltration rate (ml/s)	-0.002	0.335	-0.197
Maize yields	0.006	0.262	0.038
Eigenvalues	3.095	2.822	1.470
% of variance	30.947	28.217	14.696
Cumulative	30.947	59.164	73.860

Extraction method: Principal component analysis. **Rotation method**: Varimax with **Kaiser Normalisation**. Rotations in five iterations

Table 5.5 Varimax rotated factor loadings (principal components) matrix

Variables	Component		
	1	2	3
% Organic Matter	0.982		
% Organic Carbon	0.971		
% Nitrogen	0.966		
Bulk density		0.912	
Infiltration rate (ml/s)		0.819	
Soil erosion (kg/40s.m.)		0.785	
Maize yields (kg/40s.m.)		0.769	
pH measured in water			0.816
Phosphorus (ug/g)			0.702
Electric conductivity (dS/m)			0.411

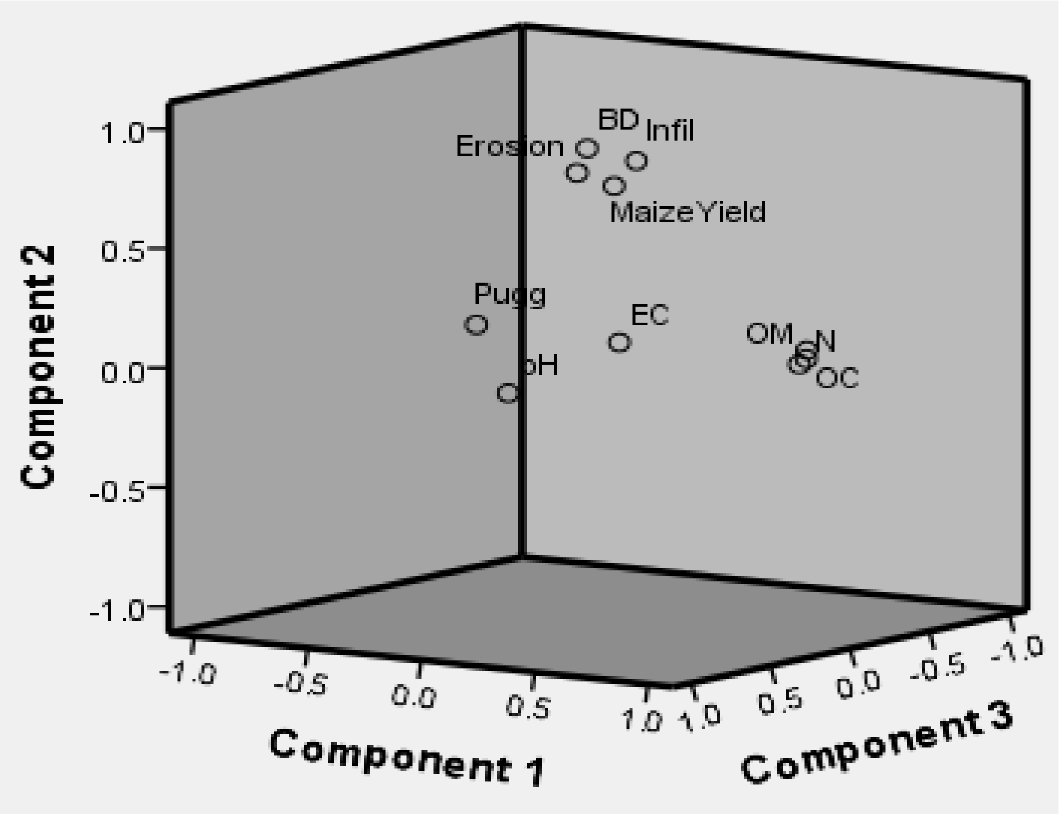


Figure 5.16 Plot of rotated factor loadings showing the three principal components

Factor loadings (Tables 5.4 and 5.5) show that OM, OC and N had the highest loadings on component 1 (PC1), accounting for over 30% of the variance. This suggests that the first component principally represented a combined change in the extent to which farmers were able to retain lost soil nutrients, especially OM that tends to be the key determinant of a sustainable soil system (Shaxson et al., 2014). These three variables showed high affinity towards one another with Pearson' r coefficients nearing 1 (factor loadings) relative to variables in the rest of the components, suggesting a strong correlation among these variables (Table 5.5). The second component (PC2) (Tables 5.4 and 5.5 and Figure 5.22) that explains 28.21% contained four variables (BD, water infiltration rates, soil erosion quantities and maize yields) that had the highest loadings on this component, representing a set of soil physical parameters (Table 5.5 and Figure 5.22). Like the first component, the second component shows that the four variables also had strong correlation with loadings of > 0.7.

This analysis shows that maize productivity is highly responsive to this set of variables (physical parameters) chiefly soil compaction levels (bulk density, infiltration rates) and amount of soil erosion than the rest, although the extent has not been quantified. According to Kassam et a. (2017) and Steward et al. (2018), a farming system that is capable of halting physical degradation of soils and help retain the limited moisture for crops can make a significant difference on crop productivity granted the increasing negative impacts of climate variability and change. Earlier findings suggested that physical degradation of soil on smallholder agricultural farmland is the primary cause for decreasing crop productivity in SSA (Thierfelder et al., 2013a; Corbeels et al., 2014; Shaxson et al., 2014; Njoloma et al., 2016; Kassam et al., 2017). While changes in variables under PC1 take time to improve (Shaxson et al., 2014; Giller et al., 2015), PC2 results indicate that DBF can make significant improvements to soil's physical variables through its 30cm deep tillage, crop residue retention, manure and box and contour ridges which translate to increases in maize yields right from first year of its implementation.

The third component (PC3) consists of pH, phosphorus (P) and EC (chemical parameters) and explained a combined 14.69% of the variance. This set of variables does not show strong correlation with soil erosion, bulk density, or infiltration rates which, according to PC2, accounts for major variations in maize yields. While they are also critical parameters for crop growth, these variables contribute the least to changes taking place in DBF plots. In this case, what really matters in DBF plots is the combination and interaction of OC, OM, N, soil compaction parameters and soil erosion levels. Section 5.1.6 showed that the DBF has the capacity to significantly reduce the amount of eroded soils per unit area which imply that more rainwater is harvested, and moisture conserved, less soil degradation (OC, OM and N) due to loss of topsoil. It is not surprising, therefore, that maize yields are more responsive to PC2 variables relative to PC1 and PC3 regardless of the temporal differences.

Pearson's correlation coefficients at $p< 0.05$ computed in the PCA to isolate variables with the highest relationships showed significant correlations among 46 of 81 soil attributes (Appendix 3). For PC1 (OM, OC and N) and PC2 (BD, infiltration, soil erosion and maize yields) for instance, all the pairs of variables yielded strong interconnectedness such that their correlation values (r) are significant even at p< .001 unlike PC3 (pH, P and EC). Significant relationships are also present for variables outside principal components. For instance, variables in PC2 like maize yields has strong correlation with PC1 variables like OC, OM and N (p< .05) and EC in PC3. The results augment the findings and arguments according to Corsi et al. (2012), Shaxson et al. (2014) and Giller et al. (2015) that many of the soil variables do not change independent of other attributes.

5.3.2 Key impacts of the DBF on soil and maize productivity

Results in Sections 5.1 and 5.3.1 suggest that the major environmental contributions of DBF are those concerning the physical improvement of soil parameters which also show strong correlation with improvements in maize yields. Firstly, deep tillage is an important DBF component that is responsible for loosening the compacted soil. This de-compaction of soil improves rainwater infiltration and conservation, reducing accumulation of surface runoff. Consequently, soil erosion is significantly reduced, and further loss of fertile topsoil is avoided. Moreover, incorporation of manure application, contour and box ridges and associated interventions further gives a DBF plot an edge in soil and water conservation and halting soil degradation. Given all these improvements can be achieved right from first year of DBF improvements, results show that maize yields positively respond to these changes, making the DBF a better farming system relative to CR.

The ability or willingness of a farmer to commit to deep tillage, bed measurements, inclusion of contour and box ridges, manure application and crop residue retention depends on several environmental and socio-economic factors which in turn, determine the extent of benefits that accrue on a DBF plot. For instance, the DBF practice in Kapata is highly varied by only looking at two farmers: Celina and Daniel. While Celina managed to do 30cm tillage, made contour and box ridges, vetiver grass, retained maize stalks on bed surfaces, Daniel’s DBF plot is an extreme opposite of this despite being in the same area with similar soil types, topography, and rainfall etc. High infiltration rates, highly reduced soil erosion and high maize yields were recorded on Celina’s DBF plot unlike Daniel’s. Likewise, labour bottlenecks embedded in complex socio-economic conditions (detailed in Chapter 6), farmers’ resource endowments are likely hinderances to an individual’s ability and willingness to engage in any one of these DBF aspects.

Certainly, extent of benefits any one farmer can manage to harness using DBF and ability to sustain them without Tiyeni's presence is bound to vary from one individual to another and from one community to the next. Depending on soil types, rainfall patterns and topography and a farmers' ability and willingness to engage in DBF's key aspects (deep tillage, manure application and crop residue retention), effectiveness of the DBF can move towards its full potential or become like conventional ridges as Figure 5.23 depicts. Obviously, different results would be expected if completely different study sites and participants were chosen owing to complex social-ecological conditions at both community and farmer level.

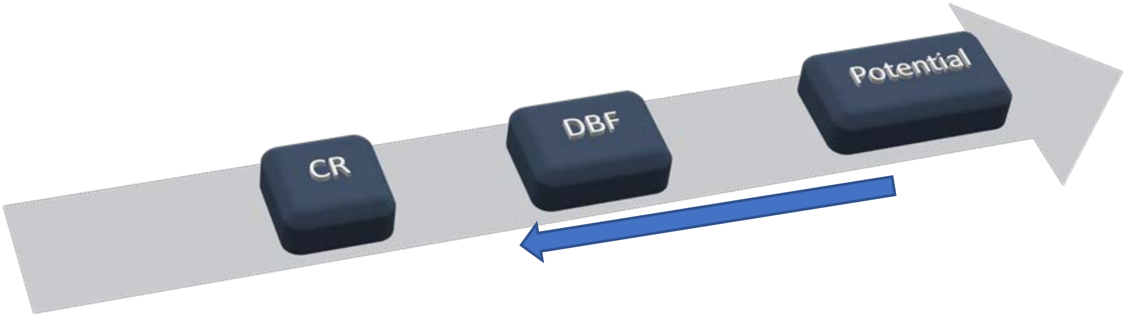


Figure 5.17 Illustration of varying extent of DBF's short-term benefits as influenced by variations in DBF practices due to diverse social-ecological conditions.

5.3.3 Sustaining DBF impacts on soil and maize yields

Comparing DBF plots across time, results show apparent decline in DBF's effectiveness in delivering the same key benefits in five-year old plots as in two-year old ones. The decline has been attributed to several challenges that make sustenance of improved soil conditions under DBF challenging. Failure to retain crop residues on bed surfaces, consistently apply manure and avoiding soil re-compaction for reasons like those that limit attainment of DBF's full potential eventually lead to rapid re-compaction of soil under DBF. The latter negates much of the improvements made in the first year of implementation. Because soil surfaces are left bare and exposed to direct sunlight, raindrops, and other harsh external conditions, five-year DBF plots showed increased compaction of soils (BD and infiltration) and reduced maize yields than two-year ones.

Field observations corroborated this where most of five-year DBF plots were found to be less than 15cm deep, desiccated, and with crusted bed surfaces, worn out contour and/or box ridges etc. In some cases, conventional ridges were found to be better maintained than DBF plots. It is no surprise that five-year DBF plots are not effective in reducing soil erosion, improving rainwater harvesting and infiltration hence maize productivity declines (opposite arrow direction in Figure 5.23).

The resilience and sustainability of the soil ecosystem requires that the net nutrient extraction rate balances with net nutrient additions (Kassam et al., 2009; Sileshi et al., 2016; Wortmann & Dang, 2020) Organic matter addition through organic manure application and permanent organic soil cover form crucial sources of nutrient addition into the soil system on both DBF and CR plots and thus are key to creating sustainable agricultural systems. Results in Section 5.1 showed negligible improvements in organic matter, organic carbon, and nitrogen in both DBF and CR plots. These results are foreseeable given that key practices that ensure their increased or constant supply are widely neglected or sporadically done in all six study sites. As much as complexity in crop residue retention and organic manure making and application is acknowledged (Section 5.2), their role in making agricultural soils sustainable and productive remains irreplaceable.

5.4 Conclusion

This chapter has analysed impacts of the DBF on key soil variables, soil erosion, and maize yield response to changes triggered by the novel farming system. It has been shown that much as the DBF is a useful practice as a sum of its parts, factors such as topography, rainfall amounts and soil types at a community level determine which of its components to include or exclude. For example, places with highly steep terrain value most parts of the system unlike in gentle to undulating slopes. Chikwina and Kapata are examples of the former where deep tillage, contour ridges with vetiver grass, closed plot edges and box ridges were found on most DBF pots as important physical features to control and reduce soil erosion besides crop residue retention and organic manure application on some farms. Representing low-lying and flat areas, the same DBF components were not so widely practised in Jalanthowa and Chipapa except deep tillage and box ridges. With sandy soils and flat terrain, Malaya Nkhata has no reason for deep tillage, box ridges or planting of vetiver given that soil type and topography in this area already perform functions that these key DBF components accomplish.

At an individual level, crop preferences, land holding sizes, age and labour availability, and previous experiences with the same or similar interventions are key factors that determine which of the DBF aspects are practised, how they are practised and ability to sustain the farming system on their farm. Granted the arduous work involved in deep tillage, elderly farmers without ability to hire labourers and limited family labour like Gladys Nkhata and Martha Munthali in Chipapa find it difficult to accomplish 30cm deep tillage, make reasonably large contour and box ridges, retain crop residues and make and apply manure unlike those in their youthful age or with some disposable income to hire labourers. Because of crop preferences and restrictions on what a farmer can grow on DBF, farmers like Elijah Munthali decided to have their DBF plot in a wetland. Combined with environmental factors operating at different levels, there are many variations in how farmers practise the DBF from one community to another and from a farmer to another. If completely different study sites and participants were chosen, entirely different results for most of the soil variables above would be expected.

The chapter has found that the DBF is effective at improving the physical parameters of the soil like rainwater infiltration and moisture conservation and significant reduction in the amount of soil eroded relative to CR. These are achieved because of the 30cm deep tillage, large surface area of deep beds and contour and box ridges which collectively loosen the compacted soil profile, harvest rainwater and keep moisture within the plot. PCA has shown that maize productivity under these conditions improves significantly despite marginal effective of the farming system on pH, P, OC, OM, and N levels. Even among farmers, such benefits of the DBF have been widely acknowledged while also highlighting diversity concerning how individual farmers practise the technology according to their social-ecological conditions.

Comparing two- and five-year DBF plots, benefits that accrue in the first few years appear to be short-lived. While still having a marginal advantage over contiguous CR plots, five-year DBF plots showed decreased rainwater infiltration, higher erosion quantities and eventual lower maize yields than two-year counterparts. Sustaining loosened soil conditions and a constant addition of organic matter and crop nutrients through crop residue retention and manure application remains challenging. Chapter 6 addresses these issues in detail.

Chapter 6

DBF's Contributions to Farmers' Livelihoods Sustainability

Chapter overview

This chapter tackles the question of DBF's livelihoods sustainability (objectives 2a and 2b). This is achieved by examining the system's impacts on food security, household income and labour dynamics, representing one element of the three social aspects of the framework presented in Chapter 3 and in the Sustainable Livelihoods Framework (SLF). The Chapter begins with providing a generalised picture of DBF's impacts to livelihoods (Sections 6.1 to 6.3) on which Section 6.4 builds to detail extent of DBF's livelihoods impacts under four categories of farmers. Section 6.5 provides analysis of complex issues surrounding limited land size under DBF and its sustenance among smallholder farmers independent of Tiyeni. This is followed by Section 6.6 which is about labour dynamics vis-à-vis DBF introduction and emerging trade-offs. Lastly, Section 6.7 discuses result and answers the livelihood sustainability question and how it relates to farmers' livelihood adaptive capacity.

6.1 Contribution to food security and income

The analysis of DBF's contributions to farmers' livelihoods using proportional piling, group discussions and individual interviews showed that farmers involved in DBF have observed or experienced improved household food availability because of improved maize yields per unit area (Chapter 5) which translates to additional household food reserves (Table 6.1 and Figure 6.1). This increases food availability especially between December and March when most of them experience food shortages. Despite not being a DBF/Tiyeni's focus (Table 6.1), farmers revealed that dimba cultivation is a reliable fall-back strategy to food shortages such that growing of crops is timed to have extra food by the time rain-fed yields run out (December - March).

> *"In the past, many of us used to eat twice a day because of shortage of maize and as a way to make the food last longer. Now many of us eat three times a day because we have more crop yields from deep beds..."*
>
> Farmer 2GMM, (2019)

Table 6.1 DBF livelihoods contributions

Livelihood aspirations	**Average score**	**Explanation**
Food security	8	High yields per unit area implies an additional stock of maize for food.
Income	4	Small quantities of crops available for sale from small plots, poor markets and lack of price bargaining power.
Dimba cultivation	1	Tiyeni does not concern itself with dimba farming. They are only interested in deep beds.
Livestock	4	Livestock pass-on program helps the poorest access livestock and animal manure.
Good housing	1	Little quantities of crops are sold amidst poor markets.
Access to loans/savings	1	Saving money is difficult because money from selling crops is very little.
Motorbikes/vehicle	0	Very few can sell crops from beds.
Fruit production	0	Tiyeni not concerned with fruit production

***Note**: in Table 6.1, 0 = no contribution at all; 1-2 = negligible; 3-4 = slight to average contribution; 5 = average contribution; 6-8 = significant contribution and 9-10 = very significant contribution.*

However, Grace contested Gospel's observation by saying that not all farmers have cattle, goats and pigs like he and his father do to cultivate a bigger land area using DBF. She pointed out that Gospel had the ability to hire labourers to work on his field amidst being an experienced lead farmer for many previous agricultural projects.

> *"Deep beds can bring food shortages if a farmer does not do it well. If a farmer doesn't dig well before making beds and they do not have cattle, they should not expect more yields from beds…"*

Farmer 2GTM, (2019)

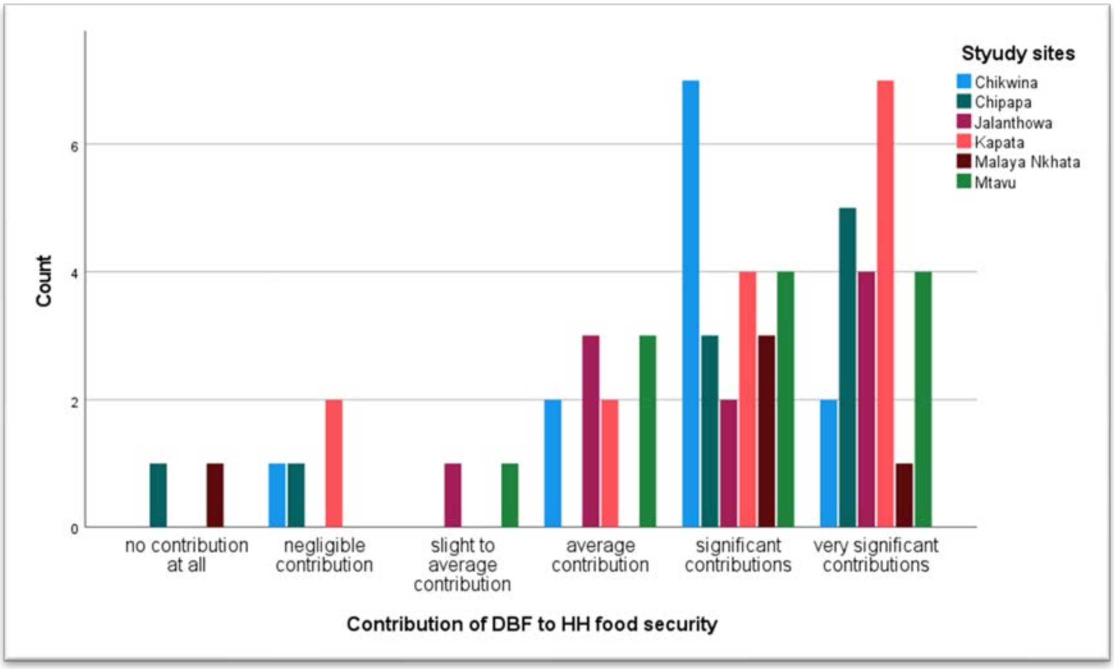


Figure 6.1 Contributions of the DBF to household food security

Other farmers have noted that introduction of the DBF on their farms has also introduced crops they used to side-line. Soya beans and Bambara nuts (*Zgama* in local language), according to these farmers, have diversified their source of nutritious food. For instance, soya can be made into a very nutritious breakfast, lunch and supper than before the introduction of DBF. Bambara nuts together with groundnuts make a delicious and nutritious relish that goes with sima.

> *"…we mix soya, maize floor and other ingredients to make Chikondamoyo* (locally made cake/bread)*. Tiyeni gave us soya seeds and so the good thing to do was to grow it. This nutritious food is good for our health. A healthy farmer is ready to do the 30cm deep tillage…"*
>
> Farmer 2GTM, (2019)

While the DBF can increase maize availability at a household level, its significance on food security depends on both community and individual characteristics. In Chikwina, their staple crop that determines food security remains cassava (Chapter 4). Increases in maize yields in Chikwina do not necessarily imply increased food security because maize is grown as a supplementary crop to support themselves in case of cassava failure due to diseases or pests. Similarly, farmers in Malaya Nkhata do not rely much on rainfed agriculture given that their soils are largely sandy and so dimbas are the main sources of food and cash crops. In Jalanthowa, Chipapa and Mtavu, increases in maize yields go a long way in meeting a household's food requirements given their dependence on maize yields, unreliable rainfall patterns that result in crop failure, generally degraded soils due to overuse and small land holding sizes for some farmers. Kapata farmers, however, own more unused land which when opened produces enough food for most households. Except for Daniel Kondowe and Luke Nkhoma, most of farms in Kapata are almost newly opened or have lasted less than four years such that manure application is often enough to correct for the little loss crop nutrients. At the individual level, significance of DBF impacts on food security as well as income is determined by a farmer's socio-economic characteristics which are presented under Section 6.4.

6.2 Contribution to household income

Despite increase in crop yields per unit area (Chapter 5), DBF's direct contribution to household income earnings is still in its infancy due to limited crop yield owing to small DBF plots and limited access to better markets. Field observations discovered that small plots sizes are a major limitation to the extent to which DBF contributes to household income even where better crop markets exist. However, some farmers still sell the little they have even where they have insufficient food due to emergencies such illness of family members or school fees among others. Of the estimated average household total annual income in Malawi Kwacha (MK) (MK651, 194.00 ≈ USD892.94, which is 2.5 USD/day), highest earnings are found amongst farmers who engage in off-farm economic activities such as brick making business (Table 6.2). Furthermore, 21.1% of the annual income is a contribution from dimba/wetland farming. From Table 6.2, the combined crop sales (DBF and CR) only accounts for 13.4% (Table 6.2). Even without separating and quantifying DBF crop sales from CR, the direct contribution to household income from DBF is minimal.

> *“We are sure our harvest from deep beds does not really improve our income. It’s just that on the same small plot, deep beds produce more yields than ridges”*
>
> Farmer 3SNC, (2019)

Table 6.2 Income sources (1MK = 0.001371USD, 10th August 2019)

Livelihood activity	**Sum (MK)**	**Mean (MK)**	**Percentage of total**
Brick making	3530000	294167	45.2
Sale of surplus crops - Dimba	1648000	137333	21.1
Sale of surplus crops – Rain-fed	1047000	87250	13.4
Formal employment	507332	42278	6.5
Others	350000	29,167	4.5
Small-scale businesses eg selling fish	310000	25833	4.0
Charcoal making & selling	210000	17500	2.7
Remittance from relatives	110000	9167	1.4
Handcraft	50000	4167	0.6
Ganyu (labour exchange)	37000	3083	0.5
Brick laying	15000	1250	0.2
Total	**7814332**	**651194**	**100.0**

Lack of better crop markets, inability to access loans and financial assistance (financial capital) is another deterrent to improved household income from the little yield available for sale. Figure 6.2 shows that crops are sold to vendors from within communities or those from the nearest towns (Ekwendeni and Mzuzu for Jalanthowa, Usisya, Mpamba, Nkhata Bay for Chikwina and Mzuzu for Malaya Nkhata). Conversely, Mtavu is far from any of these towns, but they have access to better markets owing to their previous exposer crop marketing lessons and consequent formation of a cooperative that oversees crop marketing and pricing. Large companies like Shoprite and People’s Trading in Mzuzu would want to buy crops in bulk, but this is not possible given farmers’ small plots, their subsistence production levels and dependence on rainfed agriculture. Unlike the rest of the study sites, DBF contribution to household income in Chikwina may be higher than the rest of the study sites because maize is normally grown for sale rather than food (Chapter 4).

> *"Training in marketing our crops are very scarce. We wish there were training on marketing, especially targeting farmers' groups. We could then sell our crops as a group and not as individuals. This could help us control pricing of our crops. Vendors steal so much from our hard work."*
>
> Farmer 3DMC, (2019)

> *"Being close to towns is both a blessing and curse. We can easily sell crops to vendors from Ekwendeni or Mzuzu, but prices offered are very poor because everyone wants to sell so if I try not to be flexible on price, vendors go to someone else. It's a curse because any household member can sell crops any time they are short on cash. This often leads to food shortages in the household."*
>
> Farmer 4LCJ, (2019)

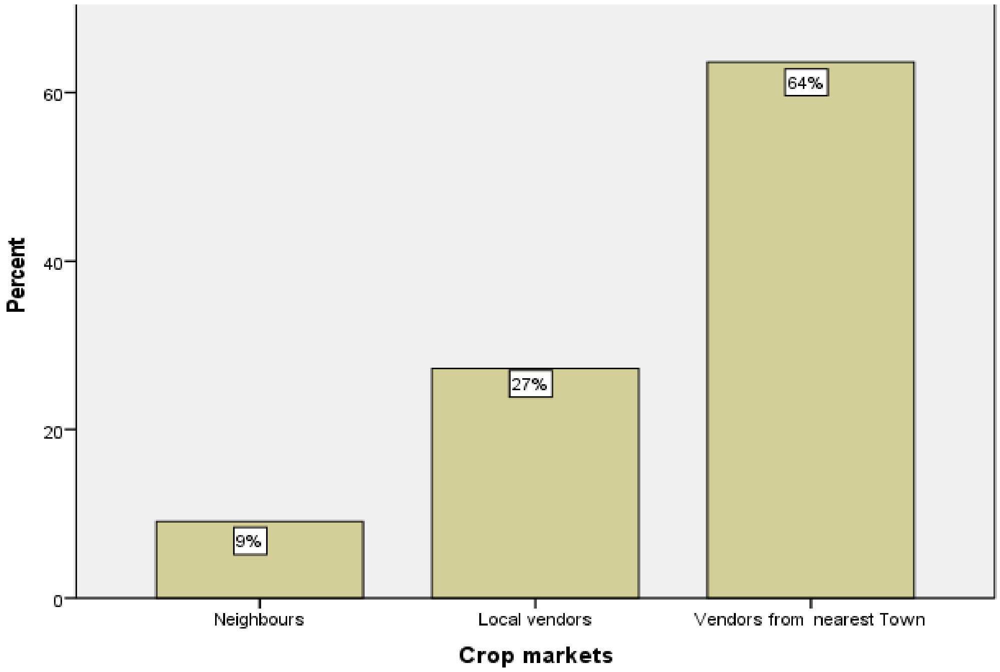


Figure 6.2 Crop markets for smallholder farmers

While farmers observed little to no direct addition of income from DBF, indirect saving due to reduction in supplementary food and inorganic fertilizer purchases has been widely reported. Because of increased maize yields per unit area, food available in the households improves for families that face chronic food shortages on a yearly basis. This reduces the need to buy additional food as they used to do before the DBF. For poor families, the elderly, female headed households, a small addition of maize goes a long way in cushioning them from yearly food shortages. Because of locally made manure, this same group of farmers also saves money on buying of inorganic fertilizers. For example, mixing 50kg bag of manure with 10kg inorganic fertilizer as per Tiyeni recommendation saves Mercy Siska over MK88,000 (US$ 118.92) since this formula helps her reduce expenditure on inorganic fertilizers from eight to four 50kg bags. Contrary, these two forms of savings have negligible impacts for wealthier farmers with ability to produce enough crops for food and income with or without DBF.

> *"Manure mixed with 10kg of NPK makes a good fertilizer substitute for basal and top dressings. This means I now buy 4 bags instead of 8. This saves me money that is channelled elsewhere."*
>
> Farmer 2MSM, (2019)

> *"Being a widow, living in poverty and raising three orphaned children is tough for an old woman like me. Despite not being able to dig a large area, the little I get from DBF using manure saves me the trouble of buying more maize…"*
>
> Farmer 1MMC, (2019)

> *"I have never failed to buy inorganic fertilizers since I began farming. My household always has surplus food which I also share with those without for free. Honestly, I did not join Tiyeni club for high yields because I can do that without it. I wanted to learn new ways of farming given that rainfall is changing these days."*
>
> Farmer 4DMJ, (2019)

6.3 Physical assets and plot sizes

Physical capital among farmers remains limited which hinders cropland expansion even where land is available. In all study sites, vital tools for cultivation are small handheld implements with overreliance on hand hoes for almost all tillage activities. This limits the expansion of land under cultivation given its associated drudgery that makes it difficult for smallholder farmers to fully utilise their available arable land.

> *"We still use hand hoes for almost all crop production activities on our farms. It is very labour-intensive to cultivate a large piece of land under our circumstances because it takes a long time to complete tillage on a small piece of land. Deep tillage in DBF makes it even harder to expand plot sizes."*
>
> Farmer 1KTC, (2019)

> *"Digging with a hand hoe requires that a farmer is in good health, energetic and well fed. You cannot dig a large piece of land by hand. Those with animal drawn ploughs are able to till a large plot in a day than those without."*
>
> Farmer 2HMM, (2019)

Figures 6.3 shows that most of the participants actively cultivate between one to five acres of land (0.4 to 2 hectares), with some having fallow land owing to limited crop production capital like seeds, fertilizers and labour. Of the total cultivated land per smallholder farmer, DBF accounts for, on average, 7% (Table 6.3). Regardless of how many years DBF had been in practice, 51% of farmers still maintained 100m^2 plots which is the size farmer start with in the first year according to Tiyeni recommendations (Figure 6.3) with only 5% of participants who extended their plots to more than this size. Moreover, some farmers, in the course of time, reduce plot sizes under DBF due to lack of crop yield improvements, unfulfilled handout expectations and labour challenges.

> "*…I would like to use the DBF plot for tobacco production this year. Since I began DBF, I have never seen the high yields everyone talks about, maybe because I failed to mulch or add organic manure. I spend much of my time on caring for tobacco…*"
>
> Farmer 5DKK, (2019)

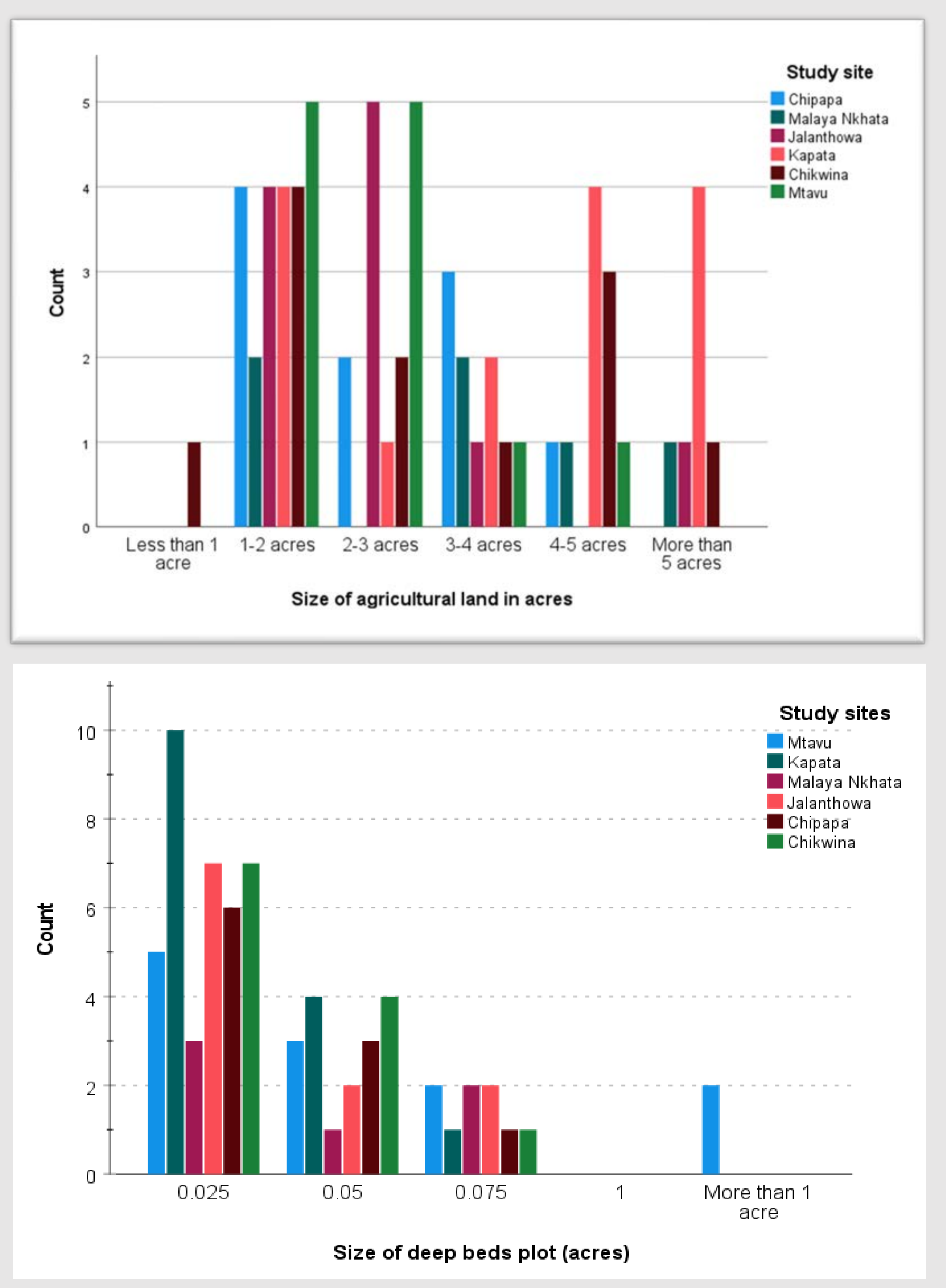


Figure 6.3 Comparison of total cultivated land (a) vs land under DBF (b)

Table 6.3 Household size and cultivated land sizes

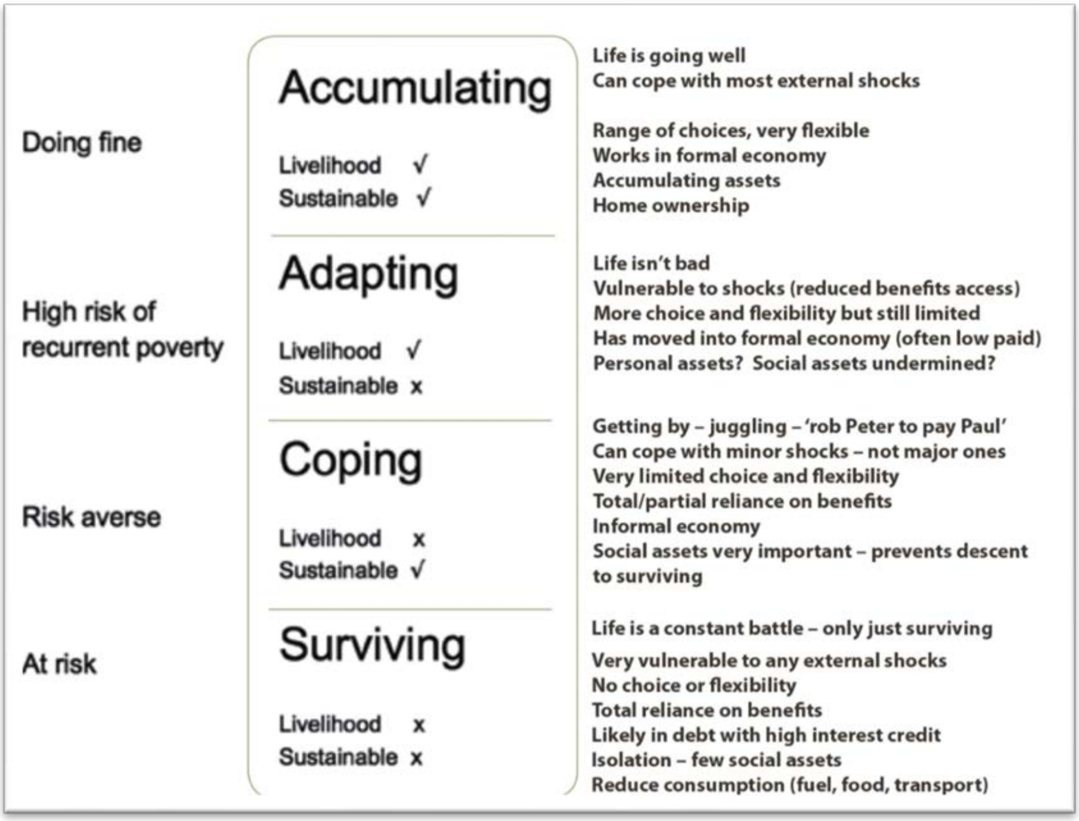
Variable	Range	Minimum	Maximum	Mean	Std. Deviation
Household size	5.0	4.0	9.0	6.33	1.92
Total land cultivated (acres)	6.0	1.6	7.6	4.38	2.13
DBF plot size (acres)	0.5	0.1	0.6	0.29	0.20
Land under DBF (% of total)	19.2	1.5	20.7	7.53	5.45

Based on the existing small plots, DBF's potential to provide high crop yields and reduce food insecurity remains unexploited. In Malawi, one adult is estimated to require three 90kg bags of maize per year (270kg/person/year). An average DBF plot then is insufficient to feed one member in a household for a year (Table 6.3). Unquestionably, increasing the land size under DBF to about half the total cultivated land can significantly increase its contribution to household food security for both poor and wealthy households.

> *"High yields on a small plot does not mean you can feed your family for a year or sell some of the crop as green maize. Since beds require small plots, you cannot rely on deep beds only for food in your household. That is punishing yourself."*
>
> Farmer 4DMJ, (2019)

6.4 Significance of DBF's contributions to household livelihoods

Apart from environmental characteristics of study sites, socio-economic characteristics of individual farmers also have profound influence on the extent of DBF's impacts on livelihoods and subsequent sustainability. Like the Livelihoods Ladder (May et al., 2009) (Figure 6.4), four categories of farmers emerge from synthesis of results above and help answer questions about what works, what does not, who benefits the most/least from the DBF and why. To appropriately allocate farmers to any of these livelihoods typologies, a scoring index was developed (Appendix 8). The index is based on the livelihoods assets and vulnerability context of the Sustainable Livelihoods Framework (Section 3.2.1) and empirical data from the 2018 exploratory study where the five livelihoods assets and the vulnerability context are assigned with numbers on a scale falling into four typologies as previously exemplified by May et al. (2009) in Figure 6.4.



Doing fine	Accumulating Livelihood √ Sustainable √	Life is going well Can cope with most external shocks Range of choices, very flexible Works in formal economy Accumulating assets Home ownership
High risk of recurrent poverty	Adapting Livelihood √ Sustainable x	Life isn't bad Vulnerable to shocks (reduced benefits access) More choice and flexibility but still limited Has moved into formal economy (often low paid) Personal assets? Social assets undermined?
Risk averse	Coping Livelihood x Sustainable √	Getting by – juggling – 'rob Peter to pay Paul' Can cope with minor shocks – not major ones Very limited choice and flexibility Total/partial reliance on benefits Informal economy Social assets very important – prevents descent to surviving
At risk	Surviving Livelihood x Sustainable x	Life is a constant battle – only just surviving Very vulnerable to any external shocks No choice or flexibility Total reliance on benefits Likely in debt with high interest credit Isolation – few social assets Reduce consumption (fuel, food, transport)

Figure 6.4 Livelihoods Ladder (from May et al., 2009, p. 14).

6.4.1 Surviving: the poorest of society

This category of farmers includes households that are the poorest of society, the elderly without or with little guardianship and female headed households (Chapter 4 and Figures 6.5 to 6.9). Principal characteristics of these households include chronic food shortages and critically low income, limited ability to cope with social-ecological shocks and pressures like droughts and food shortages, inability to afford inorganic fertilizers, and exchange of labour (*ganyu*) for money and food items. For farmers like these, a small increase in maize yields even from a small plot helps lessen the challenge of finding their next meal hence the DBF makes significant contribution to their household food security and indirect income savings through manure application. For this category, benefits of high crop yields outweigh hard labour involved in deep tillage (30cm), manure making etc. Should there be an alternative to the laborious hand hoe digging and reliable sources of animal dung for manure making, this category of farmers is likely to expand their DBF plots to maximise DBF's crop productivity potential, reduce their vulnerability to hunger, alleviate their poverty and move up the Livelihoods Ladder towards adapting and livelihoods assets accumulation (Figure 6.4).

> *"…being a widow with the responsibility of raising kids, manure really helps me produce food that would last for some time. I am old and I do not have a good source of income to buy fertilizers…"*
>
> Farmer 1GNC, (2019)

> *"…availability of food because of using manure is important for widows like me. I cannot afford buying expensive inorganic fertilizers and government's subsidised inputs are given to few selected individuals. I can still produce some food without fertilizers".*
>
> Farmer 3ACC, (2019)

Ability to produce high crop yields with little financial capital through use of locally made manure and other physical aspects of the DBF is immensely vital for empowering women and enhancing their subsistence livelihoods. According to UMFULA (2017) and FAO SOFA (2011), women produce over 70% of household food consumption needs given their role as home carers, but they often constrained by their lack of control over key crop production capitals like financial resources among others. The DBF affords them opportunities to grow food without relying on their spouses. This empowers them because it reduces women's reliance on men for household basic needs while also reducing gender-based violence related to men's failure to provide for their families.

> *"I think the DBF empowers women. When the woman gets more yields due to manure and de-compacted soils, she can then have her own food reserve and money to support her children. This woman then is not subjected to begging the husband for money to afford basic needs such as soap for washing kids' clothes."*
>
> Farmer 2GLM, (2019)

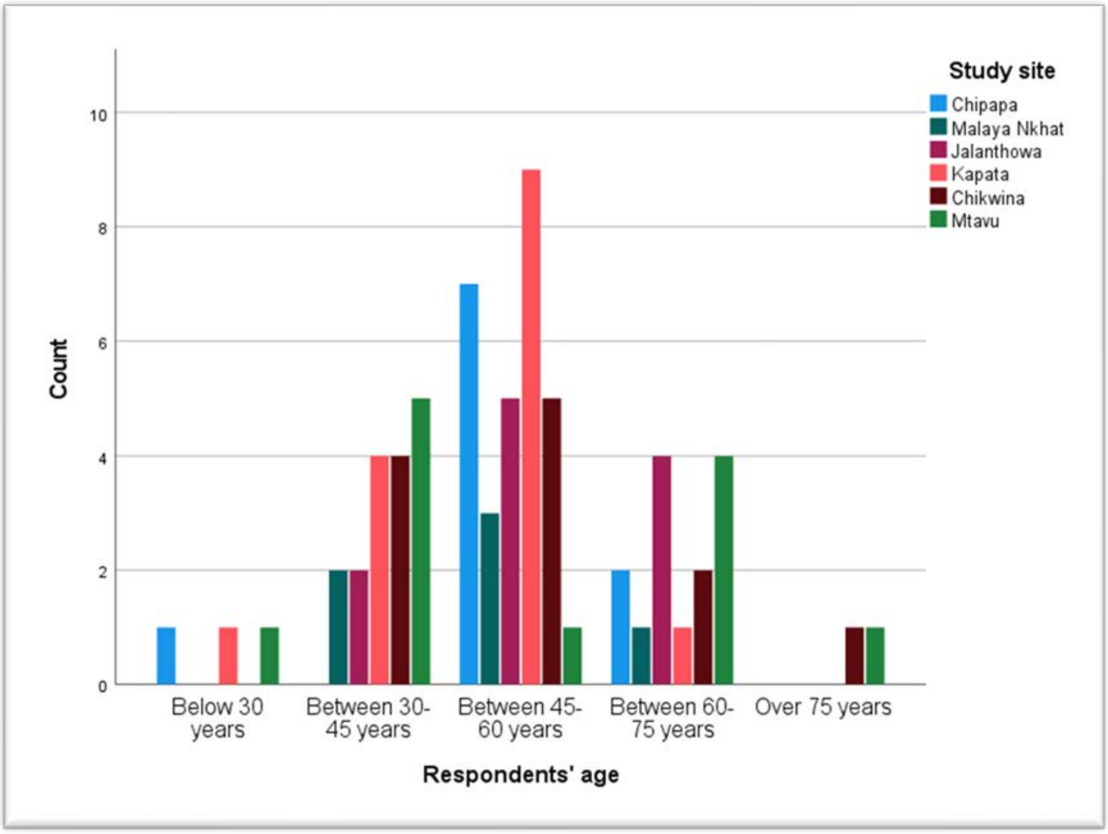


Figure 6.5 Participants' age distribution across six sites (own data)

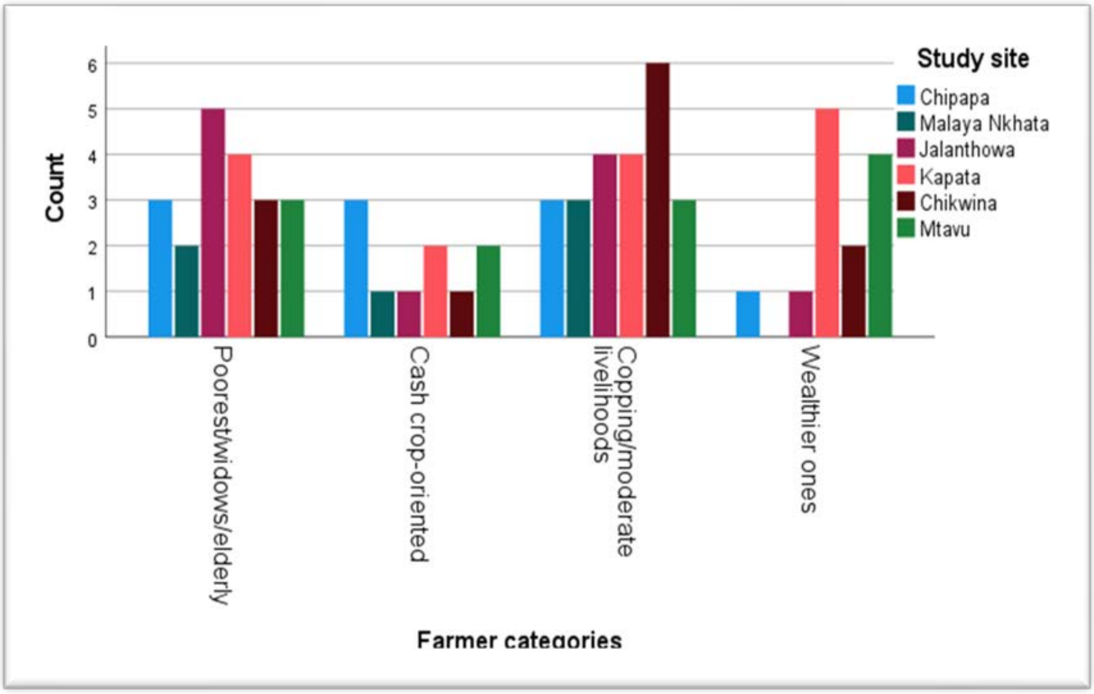


Figure 6.6 Distribution of the four categories of farmers by site (own data)

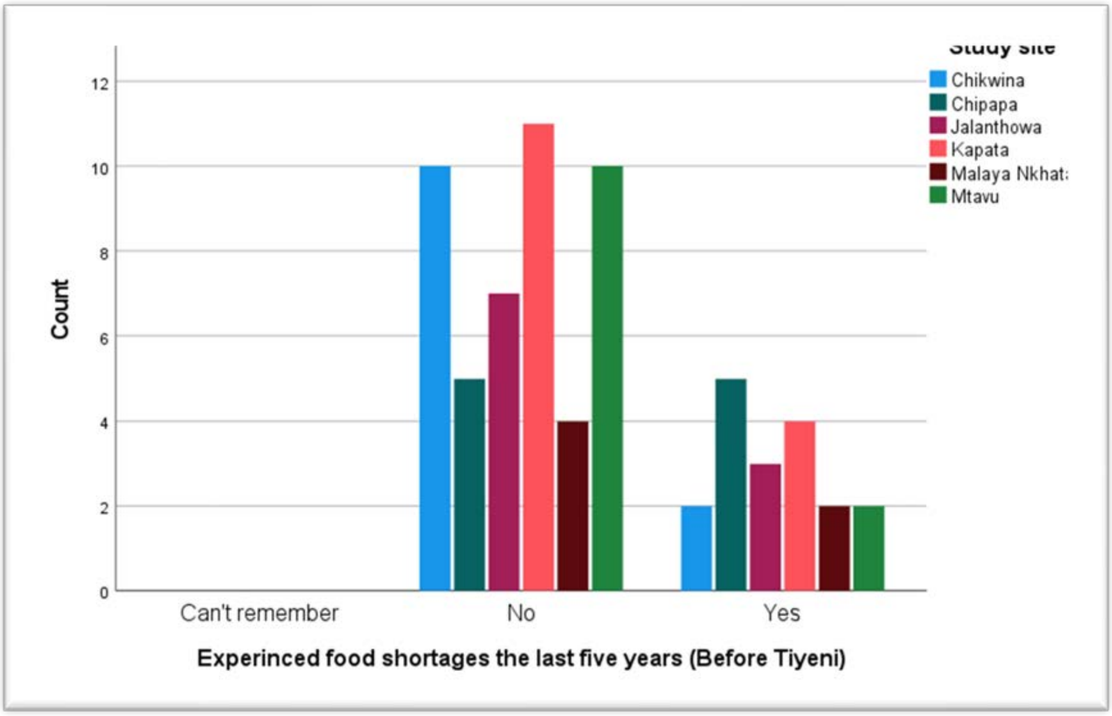


Figure 6.7 Households with food shortages before DBF (own data)

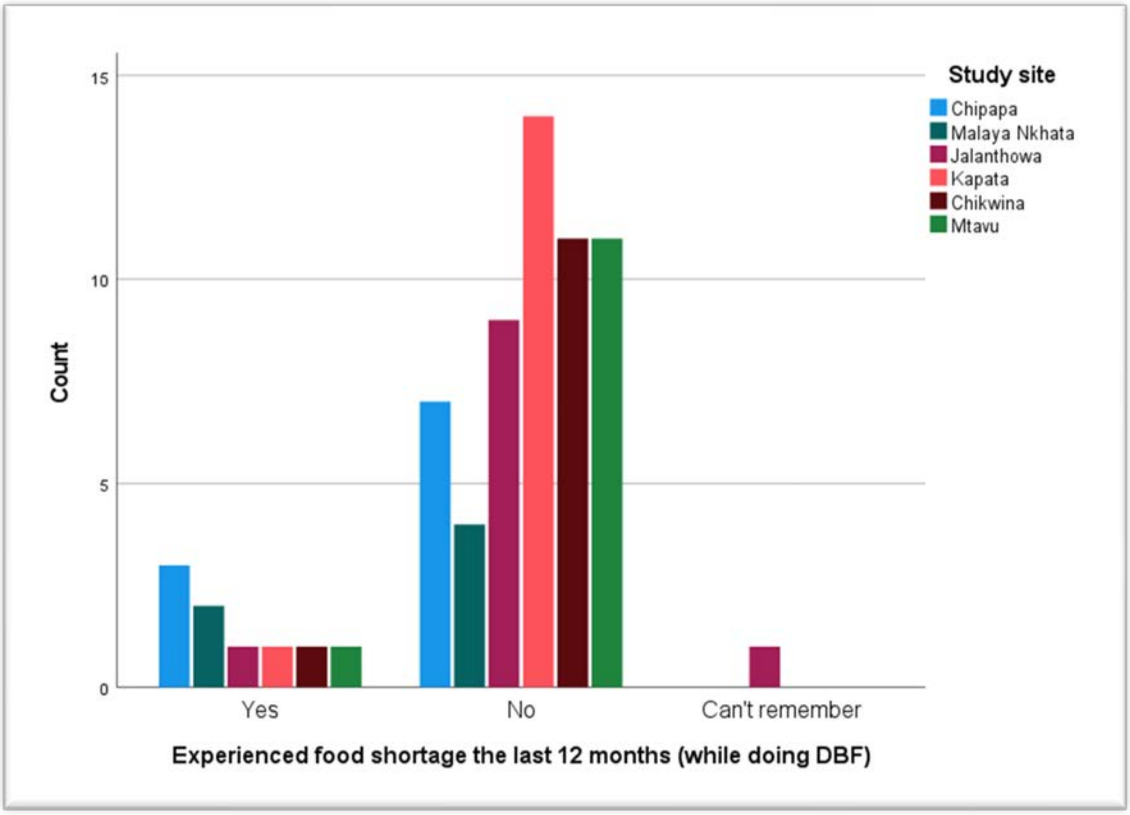


Figure 6.8 Farmers experiencing food shortage while using the DBF (own data)

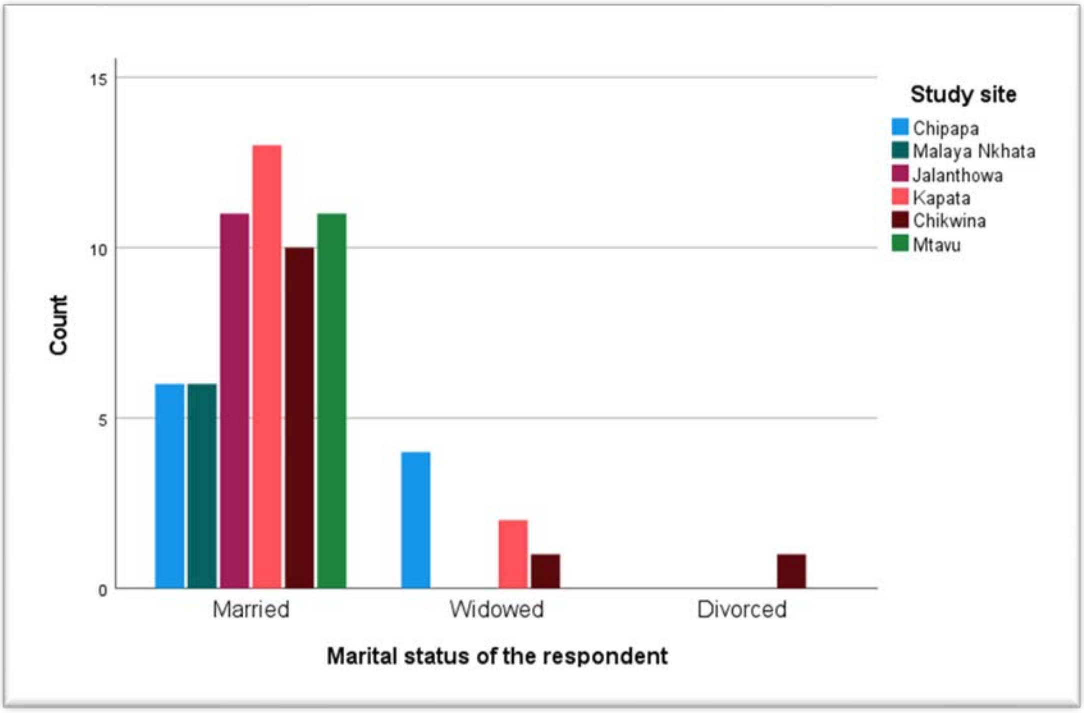


Figure 6.9 Marital status across six sites (own data)

6.4.2 Coping: Cash crop-orientated farmers

Cash crop-orientated farmers find it difficult to cope with labour demands that arise due to DBF and must make difficult choices on where to invest their time (DBF or cash crop). Tobacco is a complete yearly cycle of activities like the DBF. Consequently, these farmers spend less time doing 30cm deep tillage and bed making, often skip manure making and crop residue retention and omit box ridges. Consequently, DBF's rainwater harvesting ability, soil improvement benefits and yield improvements (Section 5.1) are seriously undermined. The phasing out of funded agricultural projects (three years for Tiyeni's DBF) is likely the end of practising the technology for such farmers.

> *"I did not make manure, nor did I retain crop residues because I was busy with tobacco. I cannot do everything, so I focus on tobacco because it brings in more money…In my experience, DBF has not really reduced hunger or labour. DBF has worked for other people so I cannot blame rainfall for my poor yields. I spent much of my time caring for tobacco"*
>
> Farmer 5DKK, (2019)

6.4.3 Adapting with moderate livelihoods

This group of farmers is in constant need of solutions to their farming problems, ranging from soil erosion, poor soil fertility and crop yields and input requirements, but their livelihoods are better than the first group above. These farmers are often food secure with some livestock and dimba cultivation mainly as a risk diversification strategy and coping mechanisms. Looming risks of crop yield reductions due to the above challenges makes it worthwhile to engage in other improved farming systems in search for information to making their farming and livelihood systems more resilient and sustainable. Such farmers often have some surplus crops for sale, thus contributing to an increased income level. Granted that DBF directly resolves their specific challenges like soil erosion, soil fertility degradation, these farmers are found to expand land under DBF and invest time and money in the modern technology.

> *“My land is located on a steep slope and so I experience massive soil erosion, soil infertility and reduced maize yields. I have been trying to deal with this problem for years. Now, DBF is just what I needed. Therefore, I am expanding land under DBF every year… Dwindling maize yields every year made me think of opening new farm. I do not have to do that now. With the cattle, pigs, and goats I have, DBF gives me all the extra yield I needed”*
>
> Farmer 2WMM, (2019)

6.4.4 Accumulating: wealthy farmers

Wealthy smallholder farmers normally have enough production capital to afford improved seeds, inorganic fertilizers, hire labourers and have increased livelihoods assets like livestock (cattle, goats, pigs), socially connected with access to up to date agricultural information. Coupled with off-farm income like formal employment or lucrative businesses like running taxis or maize milling, such farmers can cope with most of shocks and pressures. While DBF’s potential to improving soil and water conservation and crop yield increments could be more pronounced among these farmers given their ability to till a large piece of land, crop residue retention and making of manure through hiring of labourers, these farmers are often caught up in off-farm activities. Granted that DBF is a new practice and requires dedicated training to properly implement, hiring of labourers to work on a DBF plot does not help matters as they (labourers) have no knowledge of the farming system. Consequently, DBF plots are left unattended and deteriorate over time. Moreover, high crop yields on first-year small plots (100m^2) remain insignificant to high production levels of such farmers.

> *"I do not spend much time farming. I am a civil servant. What I do is hire people to work for me… I had deep beds last year, but I have failed to maintain them this year. Labourers are not trained for this…"*
>
> Farmer 5LNK, (2019)

6.5 Limited land under DBF

Results presented above suggest that limited land size under DBF is a major setback in maximising DBF's potential livelihoods improvements through soil and water conservation and increased maize productivity benefits. According to consumer behaviour theory in agricultural extension and innovation adoption (Mwangi & Kariuki, 2015; Kaine, 2004; Rogers, 1983), the expectation is that farmers would, as time passes, extend DBF to the rest of their cultivated land for maximum DBF benefits. Contrary, most farmers in this study maintained or reduced their DBF plot sizes from the initial 100m^2 with few extending them. Group discussions and interviews focused on why farmers have small DBF plots despite observed benefits.

6.5.1 Influence of start-up packages

Spreading along news of DBF's potential for high crop yields and soil and water conservation among smallholder farmers is Tiyeni's provision of start-up packages for first-time DBF farmers. In-depth interviews revealed that, to some extent, formation of all six Tiyeni clubs (treated as study sites herein) was influenced by the need to gain access to fertilizers, seeds, and hand hoes. Because the free package is only enough for a small start-up plot (100m^2), farmers often concluded that they only need that small plot for practising 'Tiyeni's DBF'. Responses to the questions "why did you form a club?"

And “why do you still have the same size of DBF plots as those you started with?” revealed similar reasons behind limited expansion of land under DBF.

> *“…our friends in Bula bragged about how they benefit from Tiyeni such as seeds and hand hoes by practising DBF, including the high yields. We wanted the same here. They told us to form a group and write a letter to Tiyeni. We did and that’s how this group began in 2016…”*
>
> Farmer 5MNK, (2019)

> *“Tiyeni promised us seeds and fertilizers for our demonstration garden in 2017 after they gave us hand hoes and pickaxes. They delayed bringing these by about three months which led to late planting. Many farmers stopped coming to the group and so few of us remained. It would have been better if Tiyeni only taught us how to do deep beds without promising seeds and fertilizers?”*
>
> Farmer 5BMK, (2019)

Regardless of place, unfulfilled handout expectations have led most farmers like Ellen Nyasulu to transform deep beds into CR, reduce plot size, or invest marginal time and resources in DBF activities, leading to poorly done DBF that renders it ineffective in delivering its intended functions. Coupled with declining contact frequency between Tiyeni and farmers after three years of guided DBF practice, sustaining the new practice without material incentives becomes challenging.

> *“Tiyeni gives us only small quantities of seed and fertilizer. This makes us think that the* 100m^2 *plot size is enough for DBF. Others stopped DBF because Tiyeni failed to give them seed and fertilizer”*
>
> Farmer 5ENK, (2019)

6.5.2 Start small, expand later: the ‘10x10' recommendation

Tiyeni’s recommendation for first-time DBF users is to start small on a 10m by 10m (100m^2) plot with the assumption that farmers would expand the plots on their own terms in the subsequent years. Coupled with handouts that only cover this plot size, most farmers’ logic has been that this is an ideal size for the DBF system. Even where a farmer has resources to increase DBF land size, most of them are subconsciously held back by the thought that Tiyeni only requires a small plot size for the DBF.

> *“Tiyeni extension officer told us that we only need to have a 10m-by-10m plot, which we could expand later if we wanted. Our thinking has been that this is the recommended DBF plot size and so many of us have not thought about extending.”*
>
> Farmer 3ABC, 2019(2019)

6.5.3 Promotion of hybrid maize varieties

While promotion of high-yielding hybrid seeds is crucial, imperfect delivery of extension messages about them within the DBF extension system makes farmers think that they cannot plant local varieties on a DBF plot. Because of the power relations between donors and Tiyeni officers created by provision of start-up packages, recommendations to grow hybrid seeds given to a farmer when donors visit farmers’ plots cement the notion that Tiyeni does not allow local varieties in DBF. For farmers like Martha Munthali whose life is a constant battle for survival, hybrid seeds are unaffordable such that without external help (free seeds), the DBF plot is left idle. Conversely, Celina Thindwa selects viable local crop varieties for growing on both DBF and CR plots thus she can expand land under DBF. Interestingly, Celina has the financial resources to buy expensive hybrid seeds but prefers local varieties unlike Martha who is held back by the need to grow hybrid varieties which she cannot afford.

> *“You cannot grow local maize seeds on beds. Wazungu (white people) come from America and Britain just to visit these beds and so having local seeds on them is not befitting. These visitors also tell us not to use local seeds in these beds when they come, but hybrid seeds are expensive for a poor widow like me.”*
>
> Farmer 1MMC, (2019)

> *“Maize seed is normally selected from my previous harvest. I know which seeds are good for planting…I like local varieties for food security. When milling, local*

> *maize produces more flour than hybrids, but hybrids are good for business… Local maize can survive weevils for a long time unlike hybrids. I buy less hybrid seeds because I use more local varieties. If you have a few bags of local maize, you are sure that you have food, unlike hybrids. My local variety gives high yields too…"*
>
> Farmer 5CTK, (2019)

6.5.4 Increased labour demands

Limited labour availability due to a number of reasons also limit farmers to small DBF plots. These emanate from household labour shortages among widows and elderly, labour exchange for food or income for the poorest households, technology compartmentalisation among household members and trade-offs arising because of DBF. Labour challenges arising because of practising DBF rank the highest on the list of plot extension disincentives. Section 6.6 deals with this aspect in detail.

6.5.5 The ownership dilemma

The question of long-term CA sustainability practices in SSA given its incentive-based promotion and top-down extension approaches (Giller et al., 2009; Andersson & D'Souza, 2014) was raised in (Section 2.3). Results show that there exists a general lack of 'ownership' over DBF and that this has contributed to the failure of DBF plot expansion uptake across all study sites. Lack of DBF technology ownership is multifaceted as follows:

(a) Which crops and varieties? For whom and where?

To help maintain DBF structural stability and lessen need for subsequent soil disturbance through light tillage, Tiyeni recommends that crops involving digging during harvesting (e.g., cassava, potatoes, sweet potatoes etc.) must be avoided. Only five crops are, therefore, included in DBF training namely maize, beans, groundnuts, soya, and Bambara nuts. Farmers who prefer other crops other than these five must balance between their crop preference and what is allowed on DBF plots to avoid disappointing Tiyeni. For instance, Elijah Munthali in Chikwina prefers cassava as a staple crop thus over 90% of his land has this perennial crop hence his DBF plot was allocated to a wetland unsuitable for a technology like this one. Related to this is the issue of vetiver and cassava on marker ridges (Chapter 5) as has been evident in Malaya Nkhata, Mtavu and other communities.

> *"…in beds, do we only need to plant maize? We were told to plant maize in these beds. I am not sure if we can plant other crops too. I fear Tiyeni will not be happy to see us planting different crops on their beds."*
>
> Farmer 4LCJ, (2019)

The choice of which crops to grow determines location and size of the DBF plots. Consequently, these too influence effectiveness of the farming technology and its contributions to household food security and income. In time, farmers who do not particularly get Tiyeni visits sit back and forget about DBF and so its long-term effectiveness and sustainability are compromised. For the same lack of DBF ownership, some farmers feel constrained on crop varieties to grow on beds. For the few who feel they 'own' deep beds on their land, local seeds are an option, even where hybrids are affordable, for the benefits only local varieties provide. For farmers like Martha, who feel deep beds belong to Tiyeni despite the plot being on her land, she has no choice but force herself into buying high-priced hybrid seeds even where local varieties are readily available.

(b) What is in the name?

In all group activities and interviews, the branding of a plot where DBF is practised among smallholder farmers revealed that most of farmers fail to separate the technology from the sponsor (DBF from Tiyeni) owing to deep-rooted compartmentalisation of plots on the same farm. DBF as a farming system is commonly called 'Tiyeni Deep Bed Farming' or simply Tiyeni. Likewise, a DBF plot is widely referred to as '*munda wa Tiyeni*' (Tiyeni's plot). Because these are Tiyeni plots and Tiyeni's DBF is being practised on that plot on behalf of Tiyeni, the expectation among farmers is that such plots would be supported by technology owners (Tiyeni). As Tiyeni withdraws its free seed and fertilizer package and reduces contact with farmers, the DBF becomes less attractive for such farmers and interest to fully engage in DBF activities on their own diminishes.

This lessens DBF's effectiveness and extent of its contributions towards farmers' livelihoods.

(c) Start-up package and farmer dependence (again)

Specific to the issue of technology ownership, the expectation on the part of the farmers is to be given handouts yearly so they can properly conduct DBF activities on Tiyeni's plot (as in b above). Due to first-year arduous tillage activities (30cm deep), farmers allege that free hand hoes Tiyeni provides wear out even after tillage of a small plot. Farmers have cited this as a reason they fail extend land under DBF as extra tillage requires that Tiyeni provides them with new hand hoes. Ironically, the same farmers use their own hand hoes for opening new farmland (more laborious than 30cm deep tillage) and on ridge-based plots, demonstrating how farmers compartmentalise their farming (plots and tools) depending on their perception of plot ownership. Under this scenario, absence/presence of handouts can deter/enable DBF plot expansion, DBF system efficacy, degree of its contributions to household livelihoods and prospects of sustaining DBF's benefits and the farming system as a package.

> *"Digging in deep beds wears out our hand hoes very quickly unlike making of ridges. We need new hoes to expand the existing plots. Our small hoes used on ridges are not effective in deep tillage. It would take long to reach the 30cm depth…"*
>
> Farmer 2FTM, (2019)

> *"I would prefer that Tiyeni never promised anything. What we needed was to learn and not to be given expectations that they cannot fulfil. I think I should take time to rebuke them. They led us astray by promising us fertiliser because in the end, we had to use our own fertilisers on their beds."*
>
> Farmer 5DKK, (2019)

(d) Field rivalry among agricultural technology promoters

Retrogressive rivalry among NGOs further leads to farmers' loss of technology ownership with serious implications on sustainability of technologies being promoted. In-depth interviews revealed that because several NGOs work with the same farmers promoting similar agricultural technologies, conflicts arise where they compete for number of farmers participating in their projects using handouts as bribes in exchange for participation. Farmers have reported cases where one NGO frustrates another's project using handouts (chiefly fertilizers and seeds) given under the condition that a farmer would start practising what that NGO promotes. Recipients are expected to open a small plot of land as a commitment towards practising the new technology for which the handout is meant, eventually sliding into outperforming each other at the expense of improving poor farmers' livelihoods. Inadvertently, control and ownership of the plot where the technology is practised are lost with most farmers abandoning new technologies when such NGOs leave the area to promote their techniques elsewhere.

> *"I volunteered my land for a demonstration of no-till. I wanted to compare DBF by Tiyeni and no-till by KULIMA on the same farm. The KULIMA Project officer told me not to do that because his bosses would be disappointed. I do not know why they do not want deep beds next to their plots, but they promised our women's group capital for our village bank if we do what they tell us…"*
>
> Farmer 1GNC, (2019)

6.6 Labour dynamics

Labour saving forms an important extension message in the promotion of the DBF among smallholder farmers under two assumptions; that the 30cm deep tillage or any other major tillage activity only take place in the first year of DBF implementation and that these activities require the same level of physical strength in doing them as those in CR. Yet, group discussions and in-depth interviews revealed that, in practice, DBF is more labour-demanding than advertised. First, deep tillage is a heavy and time-demanding task that requires high level of physique unlike ridges in CR, thus under conditions of labour scarcity, those physically unfit and the elderly would choose CR over DBF. Moreover, hired labourers also charge more for 30cm deep-tilling than simple ridges in CR owing to the same reason. It also transpired that other family members are unwilling to engage in DBF activities for the same reason besides the perception that the DBF plot belongs to the member who signed up for it by joining a Tiyeni club. Subsequently, labour is often scarce even where family labour is available.

> *"My wife and I wake up around 2am to go to the field. We work from then to around 6am and then knock off to have breakfast. The breakfast is normally big. Digging is no small job, Mr Mvula."*
>
> Farmer 2HMM, (2019)

> *"DBF did not do well last year because I was sick. My grandsons refused to work on my DBF plot because it is challenging work and that they are not members of our Chipapa Tiyeni group…"*
>
> Farmer 1GNC, (2019)

> *"…the DBF needs someone to eat enough food before you can dig. The job is tough and so you need to be energetic. If you do not eat enough or do not have enough food, you will say the DBF is bad and abandon it."*
>
> Farmer 2FTM, (2019)

To validate differences in labour demands between DBF and CR, timeline activities along with group discussions were conducted. Figures 6.10 and 6.11 reveal striking differences between the two farming systems. Land clearing in July/August marks the beginning of a farming season in CR. After harvesting (April - June), farmers have the time off rainfed agriculture for other livelihood activities like dimba cultivation, brickmaking, small businesses. Contrary, there are additional activities a farmer needs to perform on a DBF plot including land pegging and measurement, box, and contour ridge construction, second weeding, manure making and application, and crop residue retention. As Figure 6.11 shows, these additional activities in DBF crop up the time a farmer needs to engage in other livelihood activities as is the case in CR.

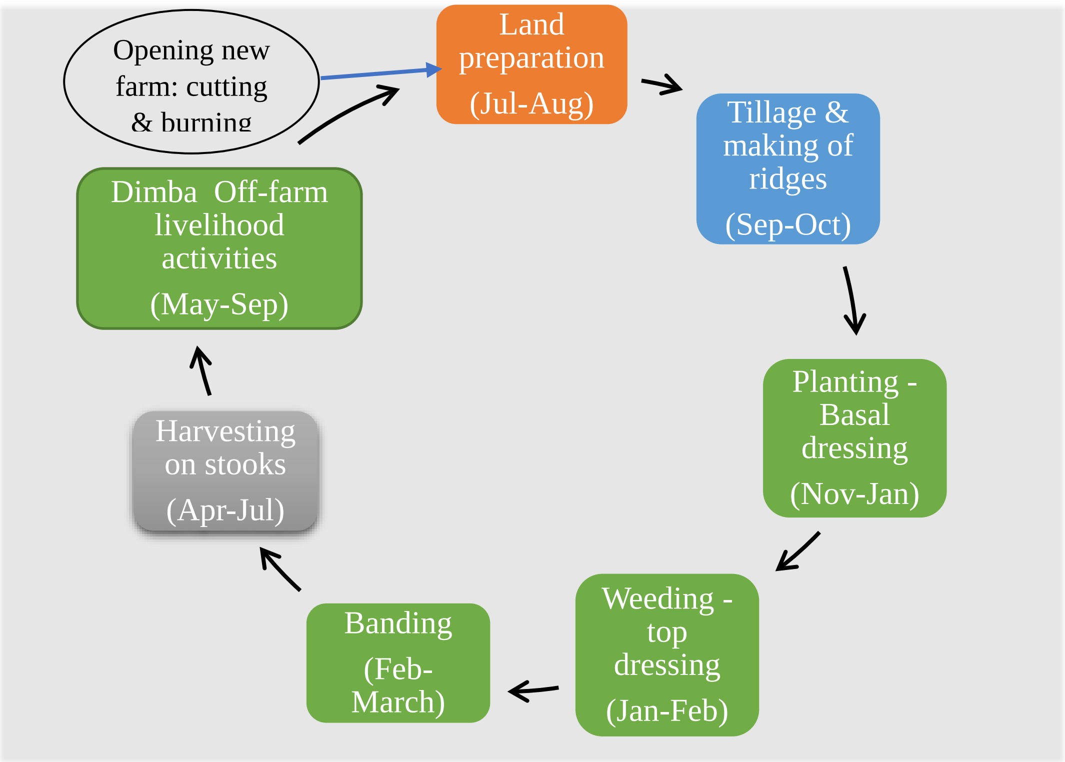


Figure 6.10 Illustration of seasonal labour activities in CR among smallholder farmers

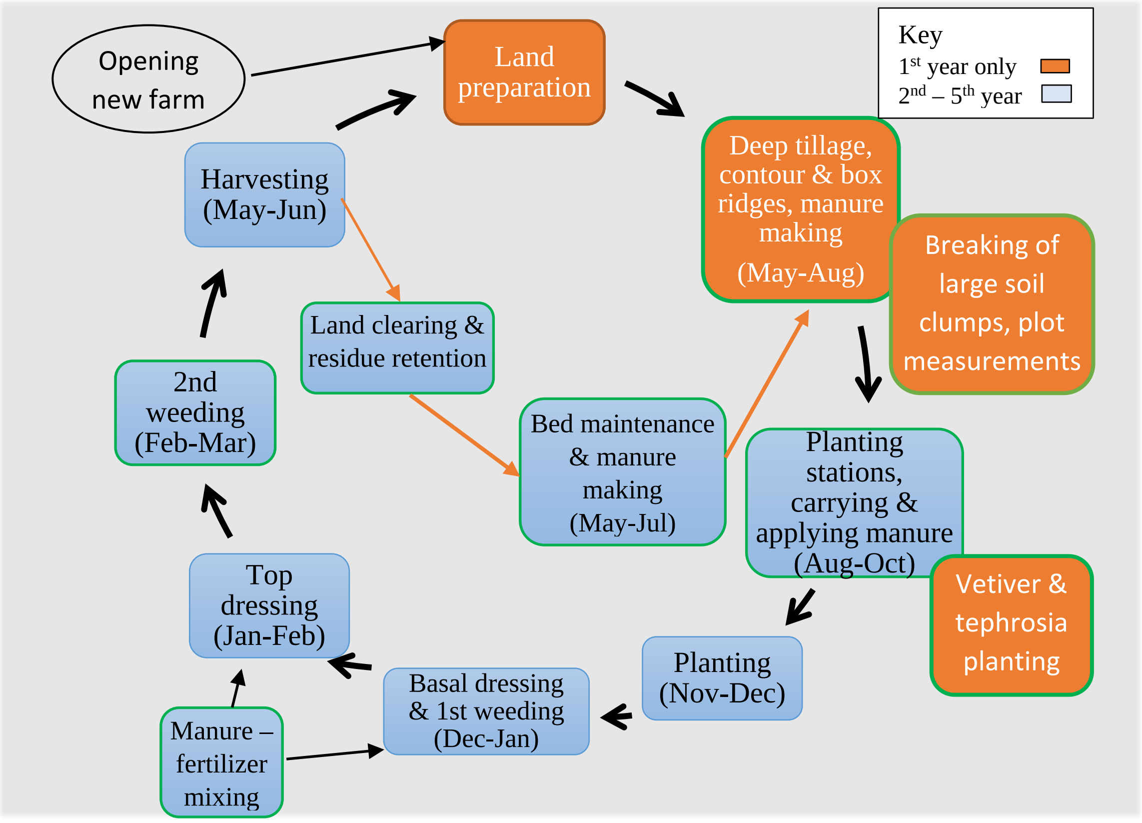


Figure 6.11 Labour activities in DBF. Additional (absent in CR) ones highlighted in green outline

> *"…this farming needs you to have labourers. You can spend all your time just caring for these beds. This is why it's wise to keep a small DBF plot size..."*
>
> Farmer 4DMJ, (2019)

> *"…you have to strategize your use of the available labour. For example, soon after harvesting, there are dimbas to cultivate, which is also a good time to dig as soils are still soft. You either forego one of them"*
>
> Farmer 5RMK, (2019)

6.6.1 Manure making and application.

Making and applying manure is another key aspect of the DBF and another time-demanding and strenuous exercise. To make manure, farmers need to dig compost pits (1m deep, 4m long and 4m wide), gather, process and mix raw materials like chopping maize stalks into small pieces, green leaves, water, grasses, animal manure, ashes, water and virgin soils. Over 15 pits of this dimension are required for one acre of DBF, requiring a considerable time investment. Transporting manure to the plot is another task normally accomplished by carrying buckets of heavy manure on their heads to plots located as far as 1km away from homes.

Manure application is also time consuming. A farmer needs to make planting stations, apply and mix manure with soil on each station by hand, marking each station with wooden sticks for easy identification during crop planting. Where manure-fertilizer mixture is used for basal and top dressing, manual mixing of two further increases time spent on manure. The decisions on whether to spend extra labour in making and applying manure or not depends on an individual's asset endowments and their circumstances. For instance, wealthier farmers like Dunstan may simply decide to purchase inorganic fertilizers and save time. Conversely, vulnerable farmers with the least assets like Gladys find manure making the only option available if they are to achieve improved food security, but all these activities may also limit size of their DBF plots and the benefits that accrue.

> *"Others fear making manure because it's a thing we are not used to doing. It adds an additional task. Furthermore, others do not have livestock for manure. Beds need manure."*
>
> Farmer 5CTK, (2019)

> *"DBF is selfish. In June, you need to have started making manure. At the same time, you must start digging and making new beds between June and September, the time you need to be cultivating your dimba. You need to start carrying manure to your plots using small buckets."*
>
> Farmer 4DMJ, (2019)

6.6.2 Bed maintenance

Lack of crop residue retention, manure application and cover crops, trampling by children and livestock leads to desiccated, crusted, re-compacted and sealed bed structures (Figure 6.12). Subsequently, DBF's effectiveness gets significantly reduced such that farmers are compelled to do light tillage activities to loosen the soil once more. This light maintenance tillage takes place after harvest and before another rainy season, which is time for dimba and off-farm livelihood activities. Farmers finding themselves under such situations keep small and manageable DBF. Preventing soil compaction and desiccation right after deep beds are made can eliminate this needless tillage activity as 5CTK's plots demonstrated (Chapter 4).

> *"Tiyeni told us we will not till our DBF plots again for the next four years. This was not true because after first year, beds needed maintaining. … we got extremely poor crop yields in the second year as soils on beds became extremely hard for any crop to grow well. We learnt our lesson the hard way."*
>
> Farmer 4DMJ, (2019)

Figure 6.12 Bare, scorched, and re-compacted deep beds in Chipapa.

6.6.3 Weeding

Weeding in DBF is a slow process owing to the use of small weeding hoes and uprooting by hand unlike in CR where a standard hand hoe with a large surface area is used. The 1m bed width also makes it impractical to weed a whole bed from one side, requiring that a farmer switches sides to complete the task on one bed, making weeding in DBF significantly slower. Moreover, application of organic manure without crop residue retention makes weeds thrive, requiring farmers to weed the same plot more than once.

> *"…organic manure, especially raw animal dung, makes weeds thrive in deep beds. With the slow weeding pace, weeds would have grown again by the time you finish the last bed on that plot. To avoid losses, I must do a third weeding. You may find that you are spending all the time on DBF."*
>
> Farmer 4LJJ, (2019)

> *"Weeding is difficult in beds. You are not allowed to walk on them and so you have to work on both sides to complete weeding one bed. Ridges are small with freedom to walk anywhere, making weeding easy and quick"*
>
> Farmer 2HMM, (2019)

6.7 Discussion

Recognising limitations of relying on per unit area yield increases as a basis for DBF's contributions to smallholder farmers' livelihoods as is commonly done in CA studies (Andersson & D'Souza, 2014; Thierfelder et al., 2014; Pittelkow et al., 2015a), a number of factors that determine extent of contributions were considered. Synthesis of results suggest that DBF's contributions to farmers' livelihoods transcend environmental characteristics of the six study sites but vary from one farmer to another depending on their individual socio-economic conditions. To this end, four groups of farmers emerged namely the poorest of society, experimenting farmers, cash-oriented farmers, and wealthy ones. Whereas general comparisons based on household size, per unit maize yields, and DBF plot sizes indicate low contributions to smallholder livelihoods overall, considering individual farmers under their unique circumstances reveal that each of the group of farmers are impacted differently.

Granted the recognition that CA does not work for every smallholder farmer (Anderson and Giller 2012; Corbeels et al., 2014), DBF's contribution to household food security is more pronounced for poorest families, female-headed households, widows, and the elderly. This group of farmers is often in acute poverty, thus purchasing of agricultural inputs like inorganic fertilizer is normally off their options list (Giller et al., 2015; Mloza-Banda et al., 2016). Inclusion of locally made organic manure for crop production provides them with a much-needed fall-back option along soil erosion reduction and water harvesting capabilities of the DBF, making significant addition to food availability from one harvest to another. However, DBF's contribution to food security remains limited due to a combination of lack of livestock for manure, unaffordable hybrid seeds and labour bottlenecks that hinders crop residue retention and plot size expansion.

Secondly, farmers looking to resolve problems on their farm, especially soil erosion, soil infertility and declining crop yields (Thierfelder et al., 2014; Andersson & D’Souza, 2014; Mloza-Banda et al., 2016) find DBF’s soil and water conservation benefits valuable. Unlike no-till systems where these benefits accrue after a long and consistent crop residue retention (Kassam et al., 2017; Steward et al., 2018), de-compaction and loosening of soils, large surface area of the 1m wide and 30cm deep beds, contour and marker ridges and manure application results in immediate soil and water conservation benefits. These short-term benefits make the DBF outstanding for this group of farmers (and the above group), lessening the burden of yield gaps commonly reportedly in no-till systems (Tittonell & Giller, 2013; Giller et al., 2015; Berre et al., 2017). DBF becomes an important intervention for these farmers, thus they often have the largest plot sizes amongst all the smallholder farmers. While DBF’s contribution to food security and income for this group may not be as high as for the poorest families above, its capacity to resolve some of the farmers’ most challenging problems like soil erosion is a long-lasting incentive for such farmers to retain its salient features beyond Tiyeni presence.

The third group of smallholder farmers is cash-crop oriented and so their inclination to produce crops not grown on DBF such as tobacco makes the DBF unattractive enterprise, amidst labour trade-offs (Anderson & D’Souza, 2014; Giller et al., 2015). Conflicting interests make this group of farmers neglect crop residue retention (Giller et al., 2009; Andersson & D’Souza, 2014) 30cm deep tillage (including subsequent maintenance) and organic manure making. By pushing these key aspects of the DBF down their priority list, the effectiveness of the DBF is negatively affected, crippling the possibility of its on-farm internalisation and sustainability, revealing the interplay between farmer priorities against those of CA/DBF proponents. For wealthier farmers, their ability to access inorganic fertilizers from off-farm income sources to produce crops denigrates the need to invest their time and labour in DBF. Their priorities and perceptions of DBF and indeed CA remain varied (Giller et al., 2015), a key component to be considered in dealing with such complex social-ecological issues.

DBF’s contribution to household level income is largely from savings on inorganic input purchases and reduction in the quantities of food a household needs to supplement their production. Savings vary from one farmer to another, being more significant for the poorest families and less so for those able to purchase inputs for themselves. Income through labour savings (Pannell et al., 2014; Corbeels et al., 2014) in DBF remains low due to the introduction of new tasks and unavailable family labour due to perceptions of who owns and is responsible for a DBF plot. Poor crop markets exacerbate the problem by crippling farmers ability to re-invest in their enterprises as they fail to get meaningful returns on their previous investments (Ngwira et al., 2012; Ngwira et al., 2014; Mloza-Banda et al., 2016). Even where good markets were available, insufficient crop yields due to small DBF plot sizes would still limit economic gains.

Derpsch et al. (2014) emphasised the need to conform to a prescriptive CA for the uniformity of extension messages to reduce deviation amongst smallholder farmers and maximise CA's potential. Results above indicate that farmers' transition from small experimental plots to fully fledged practice is, at best, frustrated by the prescriptive nature of CA extension messages that fail to recognise unique farmer experiences and preferences. For instance, high yielding hybrid maize varieties are important (Andersson & D'Souza, 2014), but they lack some qualities that only local varieties can offer, including ease of storage and ability to give more and lasting maize flour. Under conditions where hybrid seeds are unaffordable, rigid extension messages advocating for use of improved seeds may prevent farmers using their readily available local varieties, rendering the new farming systems like DBF and no-till unsuitable. Malawian smallholder farmers face challenges to access and afford improved crop seeds (Mloza-Banda et al., 2016). The perception that you cannot grow local seeds on a DBF plot and other CA practices is a strong disincentive for sustaining these technologies.

The normalised provision of handouts as start-up packages in DBF promotional projects is part of the problem derailing farmers' transition from experimental plots. The support for the provision of handouts (Ngwira et al., 2014; Derpsch et al., 2014; Mloza-Banda et al., 2016) is based on the notion that they help poor smallholder farmers to test and gain experience of the new practices. However, these handouts have contributed to the limited extension and sustainability of the DBF and CA dis-adoption in (Chinseu et al., 2019). For instance, quantities of the handouts unconsciously determine the size of, and the name assigned to plots with the new farming systems for which the handout is meant, making it difficult for farmers to perceive the new technologies as their own. Cessation of support (handouts) takes away this incentive, leaving farmers frustrated and discouraged to sustain and invest in the new practice on their own (Giller et al., 2009; Chinseu et al., 2019). Unquestionably, synergies introduced by the provision of handouts go a long way to determine the extent to which the DBF and indeed CA contributes to both social and ecological benefits for the smallholder farmer. Certainly, the best incentives for the sustainability of DBF are not handouts but its potential to solve specific social-ecological challenges for diverse groups of farmers.

Tiyeni has advanced the notion that practising DBF saves time and labour for the smallholder farmers, a similar argument advanced in the CA mainstream (Kassam et al., 2009; Ngwira et al., 2012; Nyamangara et al., 2013; Kassam et al., 2017). Findings in this research suggest otherwise. Unlike no-till and pit farming, labour requirements in DBF take divergent routes. Firstly, deep tillage is an arduous task that requires more physical strength, thus preparation of a small piece of land takes longer than in CR. Nyamangara et al. (2013) made similar observations among farmers who practised basins CA (pit farming). Secondly, the inclusion of box and marker ridges, despite playing key roles in water harvesting, presents additional labour demands relative to CR as do manure making and application, and continuous bed maintenance.

In addition to labour constraints, lack of technology ownership among smallholder farmers is a common challenge that affects size of DBF plots, labour availability, commitment to engage in key DBF activities and subsequently effectiveness and extent of contributions of the farming system to livelihoods. The perception of power, control, and ownership of how a new technology is practised on a farmer’s plot emerges from start-up packages (handouts), poorly delivered extension messages in the first few years of technology introduction, expectations of donors and on-farm visitors and competition for participants among NGOs. Despite not addressing this problem directly, Anderson and Giller (2012) and Giller et al. (2015) attempted to consider CA challenges beyond promotional projects where the farmer takes the centre stage in all CA innovation process in addition to the need to move away from a rigid view of what constitutes real CA

(Derpsch et al., 2014). These findings also confirm existing uneven power relationships that arguably continue to dominate NGO - smallholder farmer relationships characterised by a lack of devolved control of the new farming systems to farmers.

6.8 Summary

It has been demonstrated in this chapter that DBF's contributions to smallholder farmers' livelihoods, especially food security, income and labour is a complex matter embedded in social-ecological factors that influence a farmer's ability to fully harness DBF potential. The poorest farmers, despite labour challenges, are found to benefit more from DBF, seconded by farmers in search of specific agricultural solutions. Farmers solely focused on cash crops or those with off-farm income find the DBF more labour intensive and unattractive. Among others, lack of technology ownership stemming from poorly delivered extension messages, patronising visitor recommendations, handouts normalised as start-up packages and misunderstood labour challenges limit farmers' ability to extend land under DBF and sustain the new farming system beyond funded projects. The introduction of new tasks absent in CR makes DBF a labour demanding cropping system despite the potential of the system to significantly improve crop yields and contribute to farmers' livelihoods.

Chapter 7
Adaptive capacity and resilience: social capital and local institutions

Chapter overview

Access to and efficient flow of novel agricultural information and other resources forms an essential element of the adaptive capacity of agricultural systems and sustainable social-ecological systems (Section 2.4). The SLF (Section 3.2) perceives these as crucial social assets (capital) which together with local institutions (transforming structures) form what the Adaptive Cycle (Section 3.2.2) terms institutional memory. The latter is key in determining the ability of agricultural systems' ability to adapt to perturbations in the social-ecological systems (resilience) and function as knowledge reserves to aid regeneration of agricultural systems after perturbations like economic recessions, droughts, crop pests and diseases, and floods, etc. This chapter, therefore, assesses the impacts of the Tiyeni extension approach on farmers social capital and local institutions (objectives 3a and 3b, Section 1.6) as building blocks that help farmers adapt to new challenges for the resilience and sustainability of their social-ecological systems as espoused in the SLF. This is accomplished through social networks analysis (SNA) introduced in Section 3.4.

7.1 Farmers' social networks before and after Tiyeni

Given the novelty of SNA in studies like this one, this section begins by defining and describing key terms that are used throughout the chapter (Crossley et al., 2015, pp.). To fit the data into the UCINET software, names of participants were abbreviated using 'ego' to denote a farmer (participant) followed by first and last letters of their names with a number at the end to indicate the number of that participant in the dataset. For example, Loncy Chinkhuntha has been abbreviated to EgoLC5.

- **Ego:** An individual or participant
- **Alter:** Individual/entity connected to an ego (a farmer's connections)
- **Egonet:** A network of connections directly/indirectly connected to the farmer

- **Ties:** Types of relationships or connections
- **Nodes:** Shapes drawn in network diagrams to represent farmers and their connections (egos and alters)
- **Edges:** Lines in a network diagram used to connect egos and alters
- **Degree centrality:** Number of connections in an individual's network
- **Betweenness centrality:** number of bridging nodes that connect two or more clusters of isolated small networks in an egonet
- **Eigenvector:** a measure of the number of connections one ego has to influential individuals, groups, and organisations
- **Egonet density:** Total number of alters and egos in one given network

Social network analysis of farmers' connections before and after forming or joining a Tiyeni/DBF club revealed significant differences in internal social networks and information exchange among farmers after the arrival of Tiyeni (Table 7.1). Degree centrality, a measure of the number of an individual's connections, indicates that the formation or joining of a Tiyeni club provides farmers with opportunities to connect with other farmers with whom they shared no or little information/resources outside the club. Group discussions and interviews showed that some members of society like the poorest, the elderly, people with different tribal roots other than the community (Brain Mlenga in Figure 7.1), and those suspected of witchcraft are often isolated. The latter implies that such farmers have limited access to current information and productive resources essential to help them cope with, adapt to agricultural challenges, and build more resilient livelihoods systems independent of external influence. Joining Tiyeni clubs for such individuals opened new connections and provided crucial opportunities to access community resources like up-to-date agricultural information (like DBF), village banks for financial savings and loans, agricultural information for farming and a sense of belonging.

Table 7.1 Social network analysis variables (n=18)

Variable	Paired Differences Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
Degree centrality	-8.857143	8.742344	1.907736	-4.643	20	.000
Betweenness centrality	-25.230762	52.156661	11.381517	-2.217	20	.038
Eigenvector	-.140762	.157336	.034334	-4.100	20	.001
Closeness centrality	9.761905	16.136619	3.521299	2.772	20	.012
Egonet density	.017905	.113414	.024749	.723	20	.478

> *"Despite settling here for over ten years now, locals still discriminate against me in many development projects. I benefit so much by being a member of this club, especially by learning new farming techniques and sharing what I know with others who are willing to listen and share their experiences."*
>
> Farmer 5BMK, (2020)

> *"Due to my hard work and innovativeness, I have managed to improve my own livelihood. I no longer face food shortages or lack capital for buying fertilizers and seeds as before. I have bought livestock that I never had before. I have increased the size of my dimba, and I had opened a grocery store. These have not gone well with most of my neighbours and relatives, and I have since been labelled as a witch. Most of new projects pass me by because of this."*
>
> Farmer 2WMM, (2020)

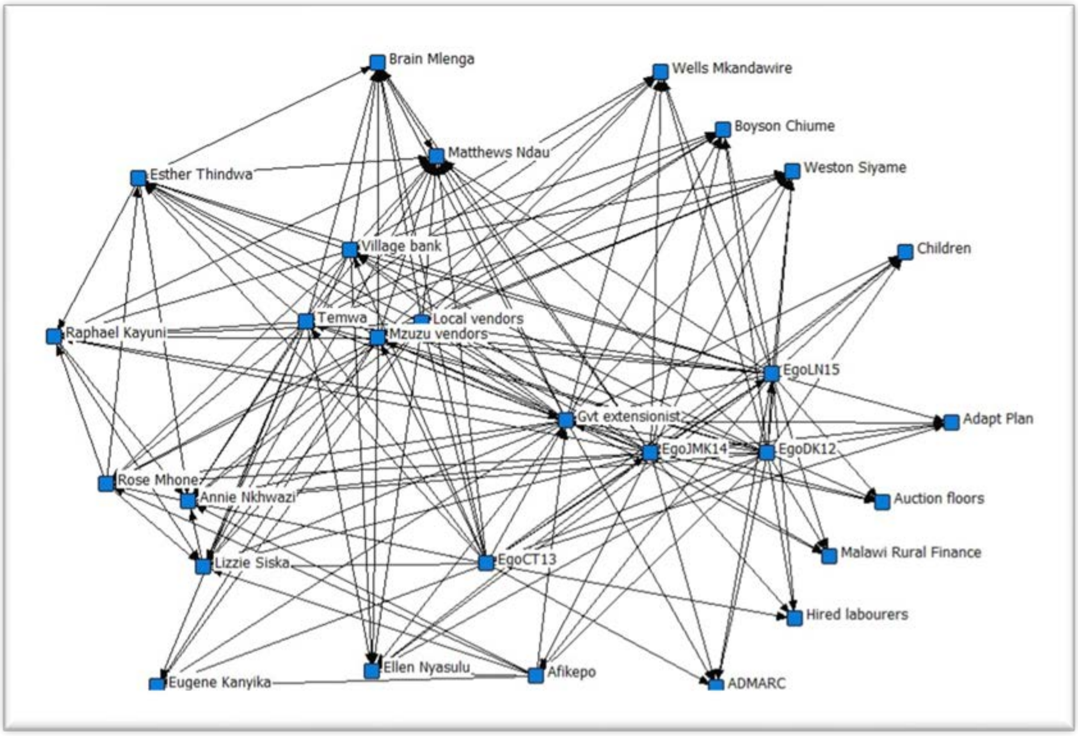


Figure 7.1 Brain Mlenga's connections after joining a DBF practising club (Kapata)

Results also reveal significant increase in the number of bridging relationships, ones that connect a localised network to an external one, a concept known as Structural Holes in SNA (Burt, 2005; 1995) as indicated by betweenness and closeness measures (Table 7.1). For example, Figure 7.2 shows bridging connections between Jane Chisi and EgoDM4’s network which affords him access to experts in livestock in Jane Chisi’s network. Through Jane, for instance, farmers connected to Dunstan in the Jalanthowa club can indirectly access information about livestock which was not available before the arrival of Tiyeni and the formation of the club. Existence of such bridging connections can enhance farmers adaptive capacity and help them build more resilient and sustainable agricultural-based livelihoods through access to novel and diversified information DBF experiences among others previously unavailable for such a group. Depending on how often and well farmers utilise their new connections, such relationships can significantly improve farmers’ perceptions of the DBF through sharing of DBF experiences on how to deal with some of the DBF’s pressing practical challenges. Social capital can also drastically reduce Tiyeni’s transactional costs in the promotion of DBF even in areas

Tiyeni is yet to reach by the power of farmers' own word of mouth as they interact with their external networks.

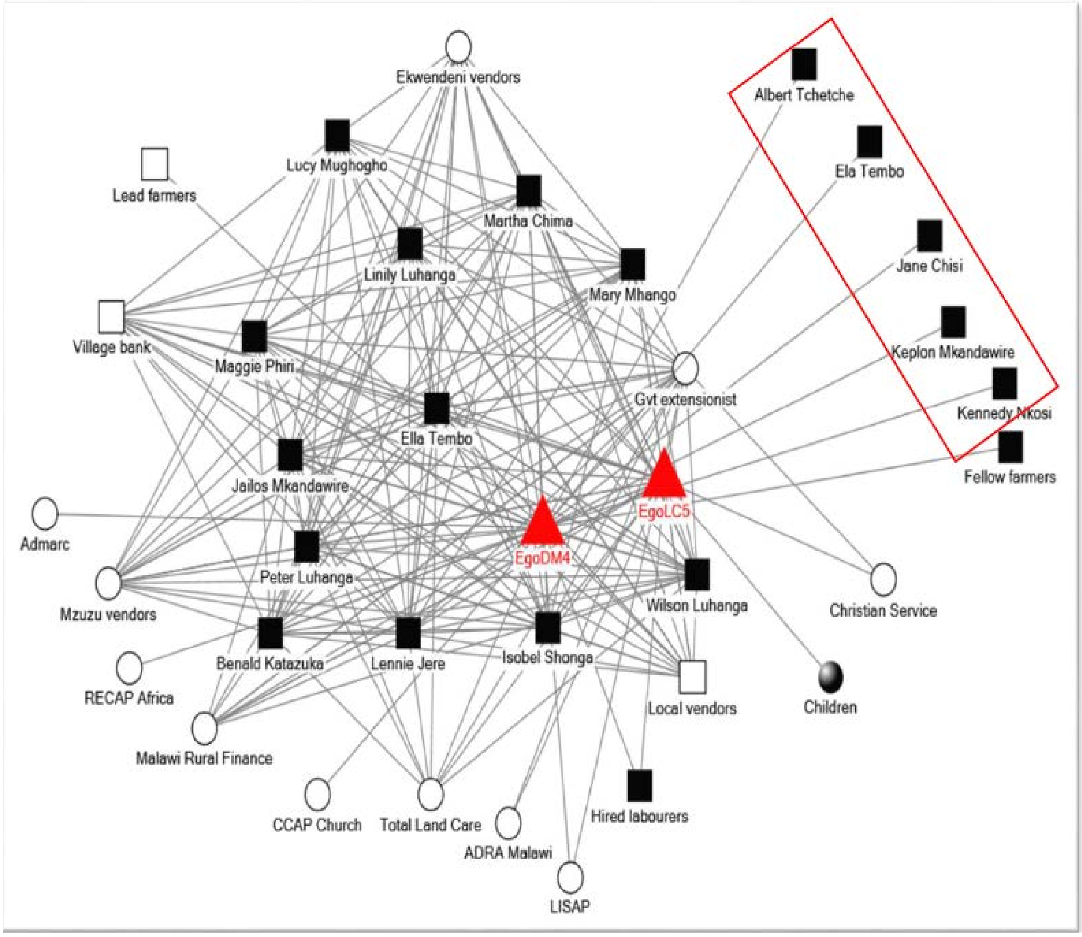


Figure 7.2 Jane Chisi as a bridging connection in EgoDM4's network.

On the other hand, results show that farmers' connections to influential individuals or organisations (eigenvector centrality) did not significantly increase after Tiyeni's arrival. According to Crossley et al. (2015), a connection to an influential community member or leader may be more valuable than a connection to a less influential individual who do not have connections to any valuable connections outside their own local circle of friends. Analysis shows that despite significant changes in network matrices (Table 7.1), influential connections for farmers have not changed. Figure 7.3 shows that the same individuals and organisations occupied central positions in these networks both prior and after arrival of Tiyeni. Effectively, the only influential actor in most of these farmer networks is Tiyeni itself (compare Figures 7.2 and 7.3).

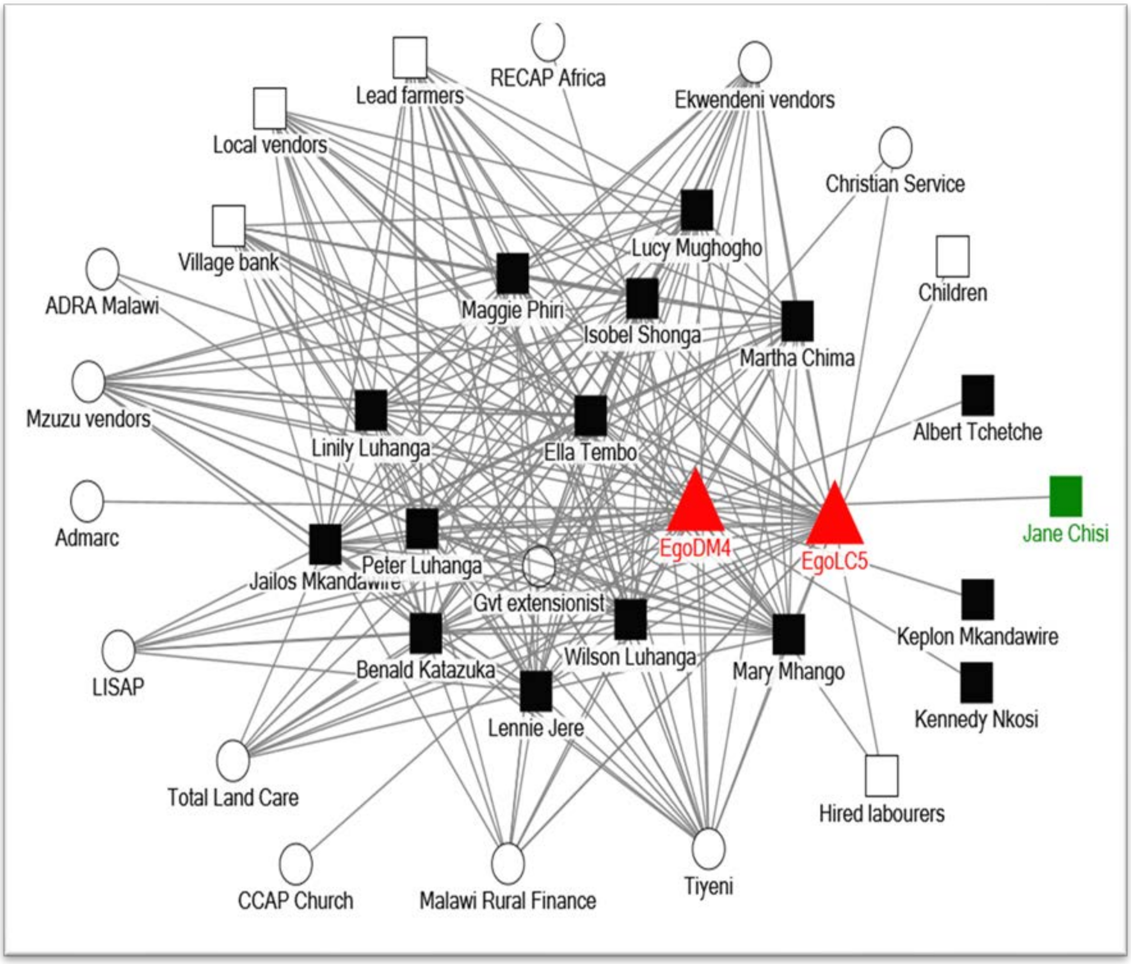


Figure 7.3 EgoDM4's network with the same members as before Tiyeni (Figure 7.2).

Correspondingly, results show that the overall network size, which is a count of the number of total network actors (network density), did not show a significant change (Table 7.1) prior to or after Tiyeni. The insignificant changes in the overall network sizes for each of the farmers imply that such networks lack additions of external members who are part of other networks other than the farmers' peers and relatives (strong ties). According to Burt (2005), strong ties (connections closest to the farmer) are crucial for individuals to respond to short-term challenges that may not require drastic and novel changes to a person's way of life. Given that these connections all share the same knowledge and draw from the same institutional memory (adaptive cycle), they do not present farmers with new knowledge which may exist in an external network. Because these farmer networks are less connected to outside communities, their ability to adapt to and sustain their social-ecological systems beyond major setbacks (trends, shocks, and pressures) is also limited. Concurrently, such communities may not be able to benefit from new farmer-led agricultural and other innovations that may be relevant in dealing with individual social-ecological challenges, thus limiting the ability to adapt and cope with emerging issues.

7.2 Access to resources: local and external weak ties

Besides understanding farmer network dynamics after the arrival of Tiyeni above, this section sought to understand who in the networks provides which type of information and resources to farmers. To do this, five types of relationships were specified namely those from or with whom farmers shared or accessed agricultural information, crop and livestock markets, financial savings and loans, labour sources during peak times, and food during a time of shortages. These five relationship types are important for smallholder farmers in that they afford them with novel information and critical resources that can significantly improve their livelihood assets and afford them an edge to properly respond to emerging social-ecological challenges and to adapt accordingly. This is achieved by analysing changes in the number of farmers' weak ties (Burt, 2005; 1995), herein, described as organisations, individuals or clubs who are not members of the egos' community and with whom farmers have little interactions with. Results reveal that there is no significant change in the number of weak connections before and after the arrival of Tiyeni. For instance, Figures 7.4 shows that the only addition to farmers weak connections before and after arrival of Tiyeni in Chikwina is Tiyeni itself.

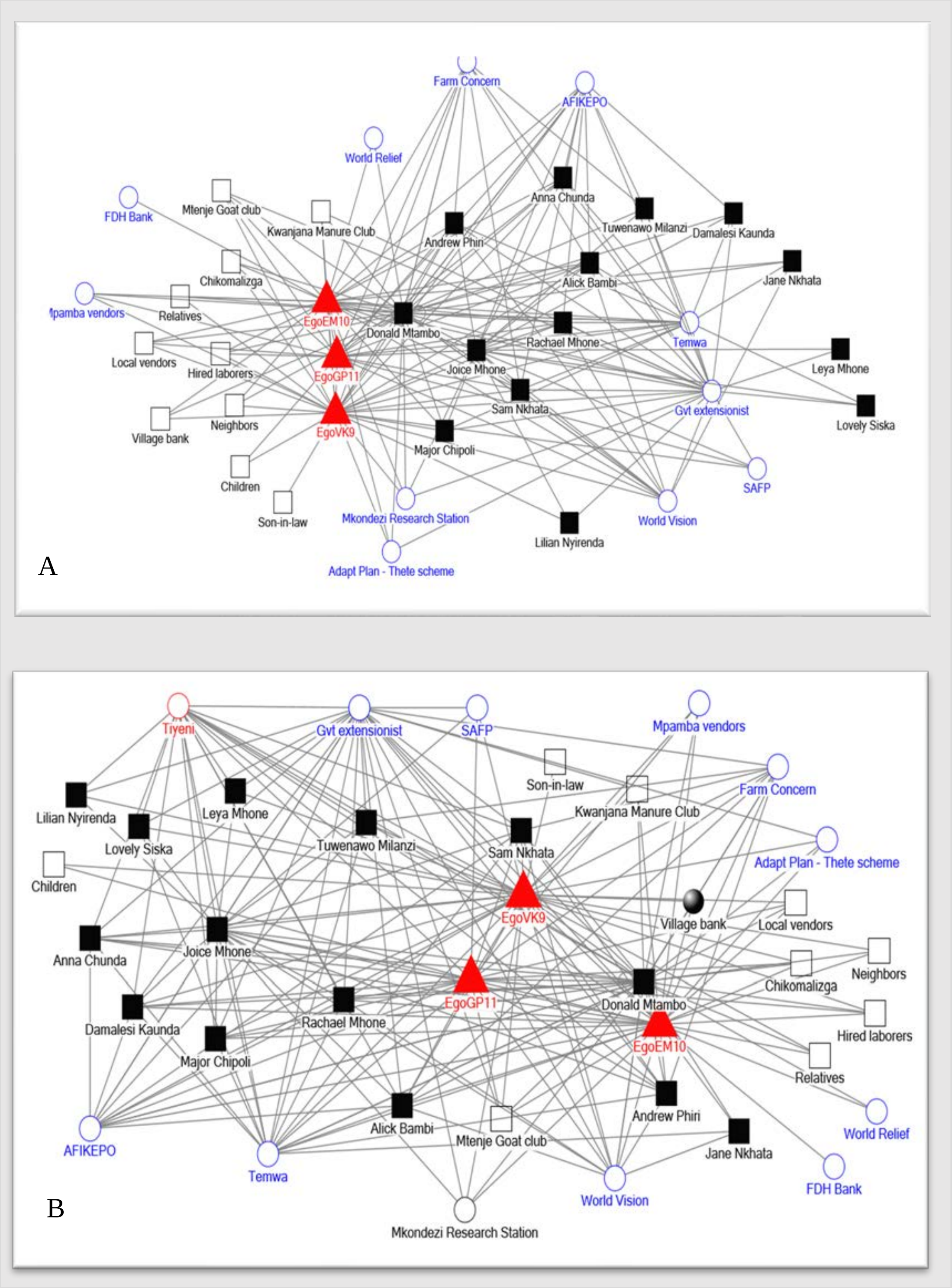


Figure 7.4 Comparing number of weak ties before (A) and after Tiyeni (B) in Chikwina.

There appears to be lack of working relationships among NGOs at the grassroot level such that, except in a few circumstances, the information they afford the farmers is the same and counter-productive at best (see field rivalry in Chapter 5). These results are typical of the existing and previous CA and other rural development projects which seek to promote one technology with pre-designed project deliverables that fail to consider farmers' site-specific needs and similar interventions by other NGOs. While it is important to avoid doing too much and fail to achieve key targets, the undiversified focus on one product is found to have two distinct problems: that it ignores the complexity of livelihoods and the interactions therein, and secondly, the simplistic approach to delivering DBF extension messages in the context of material incentives creates power imbalances between a farmer and Tiyeni, making it difficult for farmers to separate the technology being promoted from those promoting it. The failure to enrich farmers' social networks through weak ties is a missed opportunity that would add value to the interventions any one organisation promotes, including opportunities for adaptations and re-innovation of the practices.

7.2.1 Access to agricultural information and resources

Sharing of agricultural information is a critical component of farmers' social capital, and findings point to some influential smallholder farmers whose access to external sources of information make them occupy central positions in their communities. Donald Mtambo and Elijah Munthali (Figure 7.4) are good examples of farmers whose ability to form external connections and afford the community's latest information and resources earned them trust and mutual respect among their fellow farmers. Farmers have widely cited that they prefer learning about new farming technologies from these influential members as well as their neighbours and relatives who are also smallholder farmers like any of them than external officials like government or NGO agricultural extensionists, a similar observation among smallholder farmers in Malawi (Khaila et al., 2015; Ragasa & Niu, 2017; Khataza et al., 2018). Because of the trust and respect placed on them, their farms become quasi-demonstration gardens where other farmers passively observe and learn about novel farming practices to try on their own farms. These connections can be a win-win for both farmers learning from such individuals for adaptation and resilience of their farm systems and Tiyeni in the promotion of the DBF as a sustainable farming strategy.

> *"We do have a government extensionist here, but we barely connect with him on a personal level. Donald Mtambo does much of the extension work than him. He*

> *was also the one who encouraged me to join Tiyeni club. We formed Kwanjana club together, but he knows more than any of us…"*
>
> Farmer 3EMC, (2020)

Conversely, innovative, and successful farmers may become intimidating to their closest neighbours who become jealous of their achievements. For example, Watchman Mvula does not collaborate with most of his nearest neighbours because they consider him a witch on account that he managed to turn his poverty around without external help. In the end, the extent to which an individual's influence translates to meaningful exchange of information or access to resources for others is limited by the community's perception of that individual.

Like influential farmers, results show that farmers also learn more about new farming systems from their trusted friends, neighbours, and relatives across all communities. Farmers are more likely to accept a new farming system based on what they observe on their friends', neighbours' or relatives' farms and their day-to-day interactions. Because neighbours and relatives engage in the same livelihood activities and experience the same challenges, their word of mouth or observable results on their farms have a practical assurance that some farmers require in making decisions on whether to try and adopt new agricultural technologies like DBF. Moreover, the prevailing perception among most of these farmers is that external extension messages are impractical and merely theories for the academically inclined. This is unsurprising given widely acknowledged disparities between external agricultural experts and farmers' experiences after some time of practice.

> *"I was one of the DBF sceptics when Tiyeni first came here. I hated the fact that we had to dig given my advanced age. When I saw how good the crops grew on DBF plots compared to those on ridges, I got interested and began asking my neighbours and friends about it. I later joined this Tiyeni club because of my colleagues."*
>
> Farmer 2GLM, (2020)

> *"Some of the things organisations teach us are not practical. Book theories are good for academic people like you, not us. Not everything from books is useful for a poor farmer like me. I need something that can help me feed my family tomorrow …"*
>
> Farmer 2KMM, (2020)

Farmers are required that they approach extensionists in a demand-driven extension system in Malawi (Khaila et al., 2015), a subsector stricken with insufficient funding and understaffing. Given this scenario, only influential farmers with connections to extensionists benefit, leaving out the marginalised ones (e.g., red box in Figure 7.2). According to Khaila et al. (2015) and Holden et al. (2018), information exchange among farmers (farmer-to-farmer extension) is an effective and economically sound approach in delivering agricultural messages to marginalised farmers. Accordingly, Tiyeni can capitalise on this opportunity by enhancing information flow among farmers and encouraging activities that aim at fostering farmer-to-farmer interactions. Already, Tiyeni has an upper hand given their decentralised demonstration garden system which, if well utilised, can effectively enhance DBF institutional memory through sharing of their unique experiences and insights. As local knowledge reservoirs (DBF institutional memories), farmers can tap solutions from these should they face implementation challenges independent of Tiyeni. Consequently, this has the potential to enhance local adaptive capacity and build agricultural and institutional sustainability.

7.2.2 Crop and livestock markets

Marketing of crops and livestock remain underdeveloped in all the six communities despite promotion of numerous agricultural technologies the past two decades (Chikuni & Kilima, 2019; Zant, 2020). Except for Mtavu, farmers depend on their neighbours, local vendors and partly vendors from the nearest towns (Chapter 6). The problem is found to be two-fold: the limited quantities of produce each farmer can produce in one season and the lack of functional cooperatives and training programmes targeting capacity development among smallholder farmers. Combined, these two leave farmers vulnerable to unscrupulous vendors. Inclusion of crop marketing lessons can significantly improve this dilemma for secure and enhanced livelihoods.

> *"I tried growing tomatoes few years ago. I really had good harvest and invested a good fortune. No markets were available, except vendors who offered me lowest prices that worked to their advantage. I lost my money, time and effort. The same thing happens with other crops. You produce more hoping to make money, but you end up disappointed with poor prices."*
>
> Farmer 4DMJ, (2020)

> *"… I went to one boarding secondary school one time to ask if I could be able to supply them with beans and onions. They told me they buy in large quantities that I cannot produce on my own. They also want the produce during term time for student consumption, including the rainy season when I do not have the crop to sell."*
>
> Farmer 5JMK, (2020)

In a garlic production project under Japanese Overseas Cooperative Association (JOCA) in Mtavu, their training involved crop marketing lessons through one of an influential local trainer (Expert Banda) (Figure 7.5). These lessons transformed the group which also led to the formation of 'zone committees' that group farmers nearest to one another but overseen by an umbrella community club leadership. Through these groups, Mtavu farmers were able to enhance their crop diversification and marketing strategies to access lucrative markets as far as Lilongwe. While these farmers still face problems in marketing their crops, their local coordination and cooperation makes it easier to control pricing of their products when vendors come. Consequently, their local institutional setup is more sustainable and can adapt changes in crop market availability independent of external help. In turn, such groups of farmers may be able to improve their agricultural income, increase their investment in DBF and extend benefits that accrue.

> *"We sell our crops as a group. JOCA and Expert Banda provided us with the skills to manage and explore markets for ourselves. Since then, garlic prices are set by club committee. The committee advises members on the set prices. Vendors can then accept these prices or leave without buying our crops."*

Farmer 2GMM, (2020)

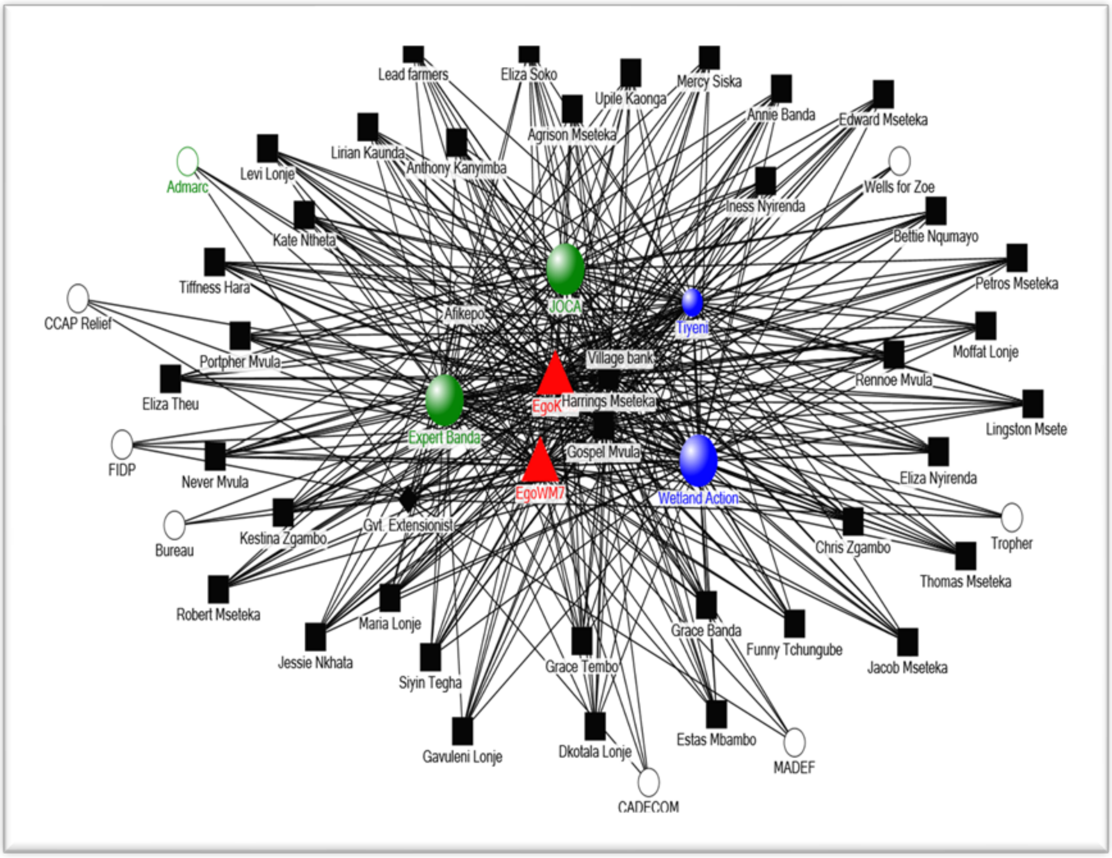


Figure 7.5 Key wetland cultivation and crop marketing in Mtavu (JOCA and Expert Banda).

7.2.3 Connections to labour sources

Besides family labour, social networks are an important means for the exchange of labour (*Ganyu*) in all six communities. While labour exchange for cash, food or material goods is an essential livelihood activity for poor families, this labour trade works much to the advantage of wealthier individuals who can afford the services. For the poor, female headed households and the elderly, free community labour arrangements based on trust and reciprocity (*Chikomalizga*) where a farmer invites their closest friends and relatives to help with farm work for a day become essential. Farmers with small networks of friends stand to benefit the least from this. By expanding farmers' connections within communities, Tiyeni farmers' clubs have become instrumental in helping the least connected farmers access this labour resource.

> *"Chikomalizga is one benefit of belonging to this Tiyeni club, especially during deep tillage and sometimes manure application… It helps poor widows like me who cannot manage to hire labourers when labour demands increase."*
>
> Farmer 3ACC, (2020)

While *Chikomalizga* exists independent of the Tiyeni clubs and activities, group discussions revealed that it was more common among two-year clubs than the five-year ones. Unlike other resources in the SLF, social capital tends to diminish the less it is utilised and vice versa (DFID, 2000; Crossley et al., 2015; Teilmann, 2015). Results suggest that as time goes by and Tiyeni-farmer frequency contact declines, these farmer clubs become less active, making it less likely that individuals who never used to interact would continue to engage in Chikomalizga.

7.3 Local institutions, farmer participation and motives

Given that functional local institutions like these farmer clubs are a prerequisite to sustainability, building on and sustaining them is a crucial step towards ensuring that farmers continue to access essential information and services to help them adapt to social-ecological challenges and to sustaining new technologies like DBF. Under this backdrop, the next subsections explore the formation and role of these clubs, their institutional set up, member participation, and the role of traditional leaders and other local institutions as they apply to DBF sustainability.

7.3.1 Formation of DBF clubs and selection of leaders

Responding to the question of how their group was established in the first place, group discussions confirm the key role both influential and bridging actors play in the process of connecting Tiyeni with various communities (Section 7.1). In Malaya Nkhata, Chikwina and Mtavu, one or two farmers discovered the DBF elsewhere and sought to see the technology introduced in their communities. These individuals helped organise their friends and neighbours into groups, elect leaders, and initiate contact with Tiyeni. Discussions with these individuals like Thomas in Malaya Nkhata reveal that good crop growth and increased yields noticed elsewhere, use of organic manure, deep tillage, crop residue retention and prospects of receiving free livestock and free inputs were critical factors that led to their decisions to have Tiyeni and the DBF in their areas. Eventually, these become benchmarks on which farmers evaluate the success or failure of the DBF and whether to continue their participation in club activities or not.

> *"Our club was formed when Madalitso Nkhata travelled to Bula for a religious crusade where he saw and talked to some of the first DBF farmers in that area. He wanted to have this technology here, so we formed a club and wrote a letter to request DBF training as required by Tiyeni."*
>
> Farmer 6TNM, (2020)

Clearly, lead farmer training is an important aspect of the farmer-to-farmer approach. Kundhlande et al. (2014) , Khaila et al. (2015) and Fisher et al. (2018) argued that primary characteristics of a lead farmer are those to do with the motivation and willingness of an individual to become one. They further found that such individuals need enough motivation through provision of material incentives tailored to stimulate their interest to disseminate the new knowledge to others. Inadvertently, NGOs have normalised provision of handouts as necessary inducements for farmer participation and technology adoption (Khaila et al., 2015; Fisher et al., 2018). Results show that the process of selecting, training, and continued participation of lead farmers in the dissemination of DBF information to their fellow farmers are highly dependent on continued provision of material benefits on the part of Tiyeni. Because of financial benefits associated with lead farmer trainings (training allowances) and proximity to source of handouts (Tiyeni), DBF trainings become attractive and selection of individuals to attend them contentious such that those less influential in the club are marginalised. At times, members without leadership positions and those not part of the lead farmers' circle have accused their colleagues of keeping handouts to themselves. Lead farmers are also accused of bias when it comes to selecting best achieving farmers to receive livestock or whose field to be visited by Tiyeni donors.

> *"I was disappointed to hear that our lead farmers who went for Tiyeni training were accommodated in open classrooms instead of lodges as other NGOs do.*

> *These are the farmers who do the hard job in the field for Tiyeni and they deserved better. I have since written to Tiyeni executive about this. Also, they did not provide allowances for attending their training which is a standard practice.”*
>
> Farmer 3DMC, (2020)

> *“I stopped being a lead farmer for Tiyeni. Instead, I devoted my time to SAFP project who think about their lead farmers and provides them with tools such as bicycles, herbicides, hybrid seed and fertilizers.”*
>
> Farmer 3SNC, (2020)

> *“Farmers like us live in the villages all the time. Why should Tiyeni choose to hold their DBF trainings in a village like Mgonapasi? We also want to go to towns, stay at good lodges and enjoy good food they provided in those places as other NGOs do. I think donors do budget for these, but responsible officers play around with that money”*
>
> Farmer 5JMK, (2020)

Notwithstanding widely acknowledged vices of handout-induced participation, smaller NGOs stand the risk of losing out their participants to wealthier counterparts as farmers prioritise immediate material benefits over technology superiority. Moreover, failure to provide incentives in form of inputs can be strong disincentives among farmers who eventually lose interest to continue practices like DBF, leading to ineffectiveness and collapse of such incentive-based extension approaches. Subsequently, dis-adoption of practices associated with these incentives and NGOs follows (Brown et al., 2017; Chinseu et al., 2019).

The negative consequences of such failures are multifaceted. The diminishing motivation of lead farmers in the farmer-to-farmer extension model counters the efforts meant to improve information flow which consequently weakens a community’s institutional memory about the DBF and other CA practices, crippling efforts to enhance resilience and sustainability of these farming systems among smallholder farmers. Except for farmers whose soil and water conservation problems are resolved by the DBF (Chapters

5) independent of material incentives, farmers become more displeased with the lack of material incentives and the infrequent Tiyeni staff visits by the passing of time. The result is the complete dis-adoption of the technology, joining of new projects that promote similar but rebranded interventions (new sponsors, new names, but same technologies!), a process that repeats itself across time (Figure 7.6). Under this scenario, DBF's adaptation and sustainability are effectively curtailed, except for individuals whose specific social-ecological challenges are resolved through it.

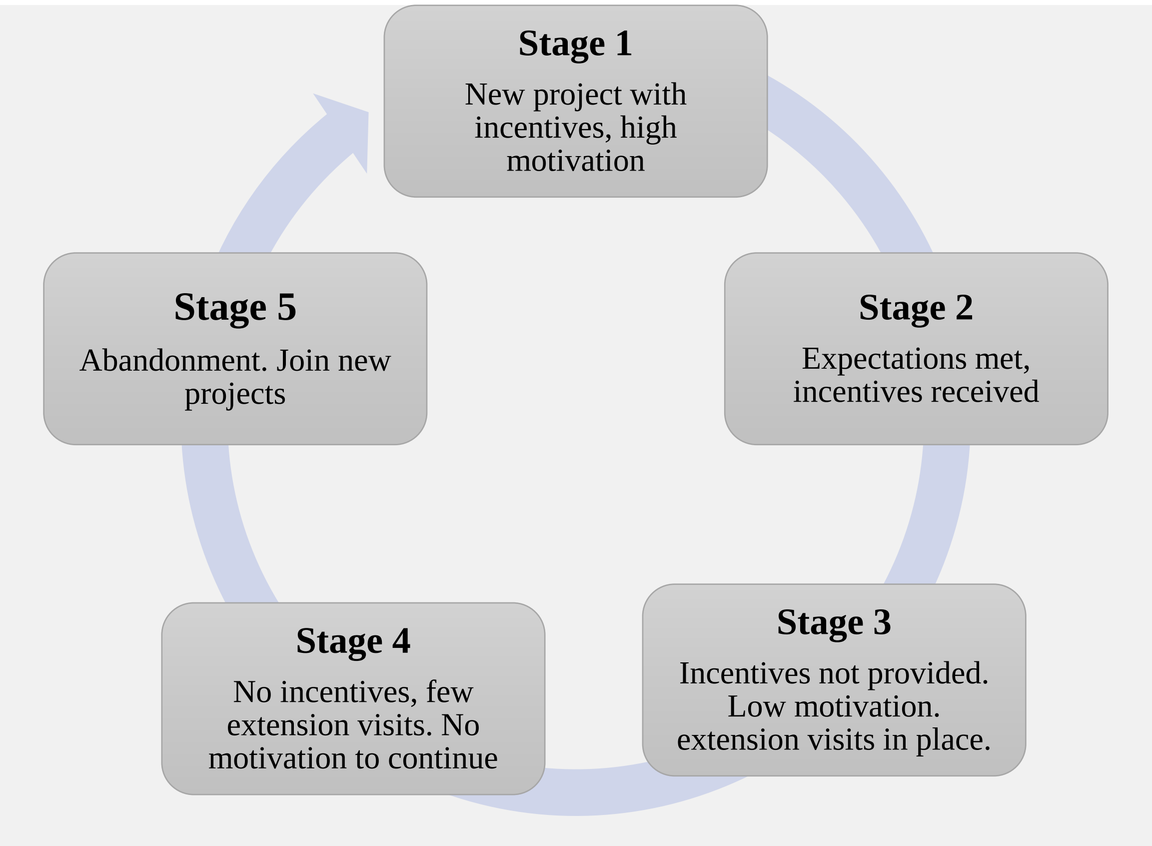


Figure 7.6 Illustrating circle DBF dis-adoption due to the influence of material incentives.

Chapters 5 and 6 highlight some of the challenges that local farmers face in relation to crop residue retention, especially due to roaming livestock and stray wildfires. Despite the many uses for crop residues, smallholder farmers do not place much value on these resources. Traditionally, colleagues and relatives have been free to graze and feed their livestock on their neighbours' fields without consultations when crops are harvested. Consequently, community byelaws are non-existent, making it impractical to protect residues soon after harvest or to prosecute known culprits of random burning of nearby bushes that cross over to farmers' fields. Except a few participants, most of the farmers think that it is laughable to get someone to the village head's court or other traditional leaders over crop residues. Similarly, group leaderships have mentioned that they have not made any discussions about such issues because of the same reasons. Correspondingly, traditional leaders have not played any role in such matters. For farmers who depend on crop residues as feed for their livestock, such matters are settled between them and the person responsible without the intervention of village leaders or group leadership.

> *"Goats and pigs are often left roaming after crop harvest. This makes it difficult to keep crop residues in fields that are closer to those with such livestock. Taking the owner to the village head because their goats or pigs ate your maize stalks is not a common practice. It would be heartless and laughable to summon a colleague before the village head just because of that!"*
>
> Farmer 4LCJ, (2020)

> *"I have not presided over any cases to do with crop residue burning or destruction by roaming livestock. These issues are common, but nobody takes them seriously. Also, I have not heard any village chief who has byelaws for such issues, maybe because we do not use written laws in the villages or because animals are supposed to graze freely after crops are harvested."*
>
> Farmer 1KMC, (2020)

> *"Someone's goats destroyed my maize stalks which I give to my dairy cows. I confronted him myself because there are no set platforms to settle such matters. I am the group's chairman, but we have never had any discussions about these problems. People are not willing to make enemies because of crop residues."*
>
> Farmer 4DMJ, (2020)

Livestock pass-on programme highlights weaknesses and ineffectiveness of club leadership and their dependence on Tiyeni for conflict resolution. Disputes arise due to the unwillingness of other members to take time and resources to care for the livestock, leaving the responsibility with the individual on whose home the livestock pen is located. In the end, the one doing most of the work feels entitled to full ownership of the club livestock. Also, some livestock get lost, attacked by wild predators and diseases that lead to their death. These issues lead to serious group conflicts such that some club members withdraw their group membership while others seek Tiyeni's intervention. The expectation would be that such issues are resolved among farmers themselves through their club leadership. Given that they are also beneficiaries of the same programme, club leaders become interested parties and therefore unable to help resolve such challenges. Local institutions such as village heads among others are absent in all these challenges.

> *"…The chairperson was left to feed and care for the pigs alone. He later wanted all the pigs for himself. Some members were not happy about this, so they left the club and stopped practising DBF altogether. We reported the issue to Tiyeni because they provided those pigs for all of us, not the chairperson only."*
>
> Farmer 1GNC, (2020)

Such scenarios demonstrate the limited capacity of local leadership for problem-solving capacity, lack of ownership of these interventions and farmers overdependence on Tiyeni, making it unlikely that these farmer institutions would remain functional without Tiyeni. This is unsurprising given that formation of such clubs is premised on gaining access to DBF trainings and handouts only despite their potential to become prime channels for farmer-to-farmer knowledge sharing for building locally suitable resilient agricultural systems that may incorporate the DBF as one key intervention towards achieving sustainable livelihoods. Strengthening these local clubs into functioning and permanent local institutions would be a win-win for both DBF sustainability and farmers' access to other resources like better markets through a unified front (as cooperatives).

According to Hermans et al. (2017), successful internalisation of sustainable agricultural practices requires a multi-stakeholder approach even at grassroot level where farmers operate. Besides farmer clubs, local leadership beginning with village heads and their committees like Village Development Committees (VDC) (Figure 7.7) can significantly contribute to DBF institutional sustainability through conflict resolution, creation of community byelaws to guide challenges associated with crop residue use, wildfires, and roaming livestock (Leeuwis, 2000; Hekkert et al., 2007). The engagement of the local institutions remains weak since they are excluded from the project initiations as groups of farmers organise themselves to form clubs (Neef & Neubert, 2011), hindering them from actively supporting the implementation process of the DBF.

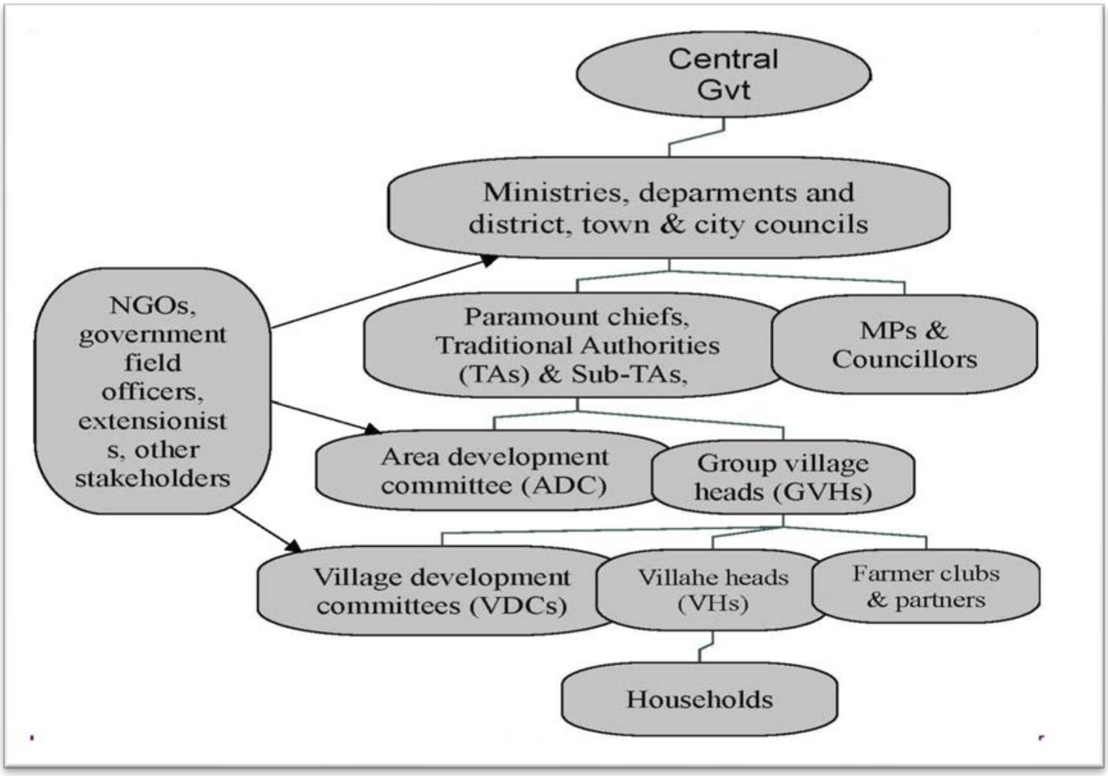


Figure 7.7 Local institutional hierarchy in Malawi for potential cooperation.

7.4 Chapter conclusion

This chapter has shown that there is incidental increase in farmers' local social capital due to Tiyeni's presence and interactions with smallholder farmers, making farmers who never used to share information or resources initiate meaningful conversations. The institutional setup of farmer clubs inadvertently creates opportunities for farmer-to-farmer DBF experience sharing while also connecting the marginalised groups (poorest, elderly, widows etc.) to sources of current agricultural information, community labour and sense of belonging. Given the lack of institutional focus to strengthen these local clubs and any meaningful attempt to engage local authorities, such improvements in social capital and associated benefits are short-lived and often diminish with time as Tiyeni reduces its contact with farmers. Consequently, collective learning among farmers of the same community becomes less effective, weakening farmers' ability to learn from each other to enhance resilience of their agricultural systems.

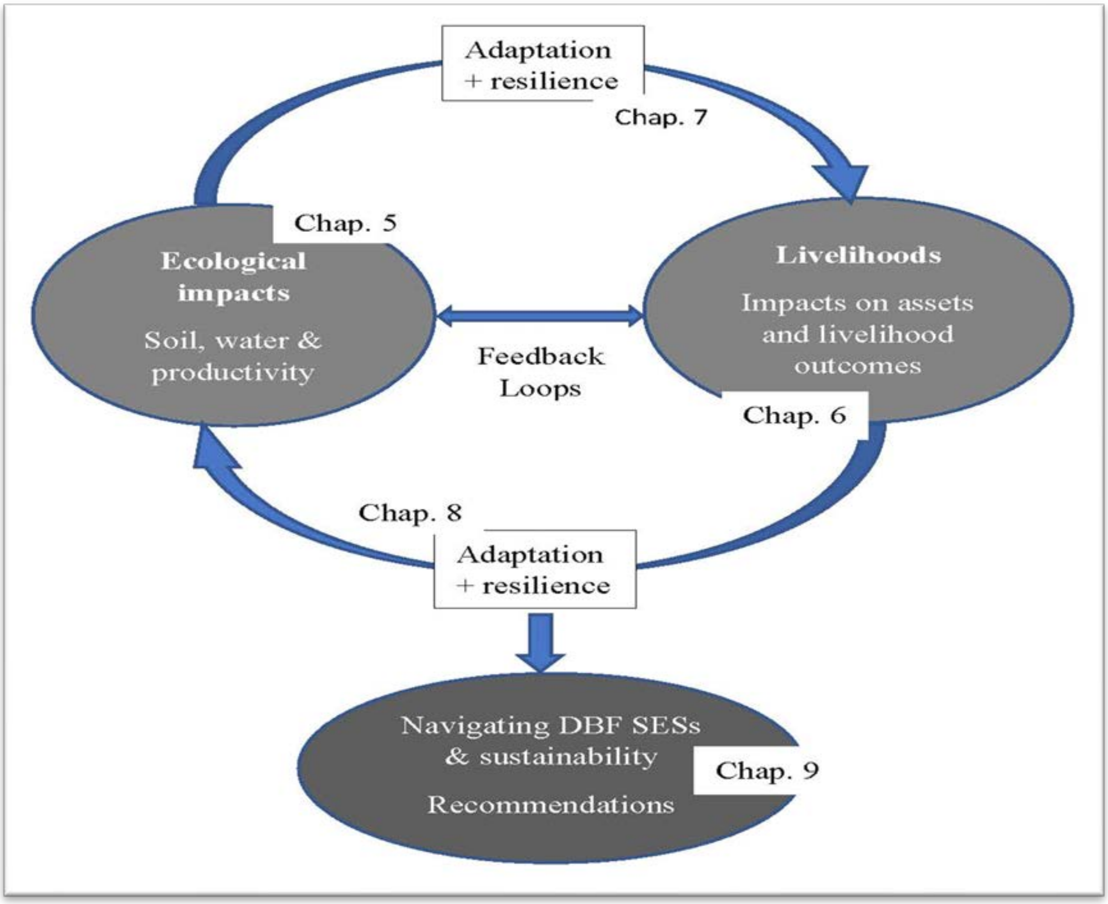


Figure 7.8 SESs model for investigating the DBF (from Chapter 3).

Besides lack of institutional focus, results suggest a lack of information diversification as NGOs operating in the same communities tend to provide the same information and engage in similar interventions under different brands (their own NGO names). Consequently, short-term increase in social capital does not translate to increase in current information previously unknown to farmers, making it unlikely that smallholder farmers would adapt their agricultural systems towards more resilient and sustainable social-ecological systems. Moreover, the importance and role of social capital and functioning local institutions are mired in complex power relationships created by material incentives that shift farmers' attention from co-learning for adaptation and resilience to short-term handouts. Creating thriving local institutions besides farmer clubs can provide a conducive environment for new innovations and co-learning opportunities among smallholder farmers which can significantly enhance local adaptive capacity and shape site-specific DBF sustainability. The next chapter provides analysis of how farmers adapt, modify, and re-innovate the DBF which forms the second part of DBF SESs model presented in Chapter 3 and reproduced above (Figure 7.8).

Chapter 8

Adaptive capacity and resilience through farmer experimentation

Overview

The ability to increase capacity for learning and adaptation and for re-organisation when a farming system is subjected to shocks and pressures (Chapter 3) are two of the three fundamental characteristics of a resilient and sustainable cropping system (Kanyama-Phiri et al., 1998; Bellon, 2001; Darnhofer, 2003; Snapp et al., 2019). Experimentation provides smallholder farmers with localised and context-specific learning through practice and adaptation from which they learn to respond to and understand more about the stressors and perturbations at any specific point in time (Cutter et al., 2008; Grabowski et al., 2018). Chapter 2 (Section 2.4.6) argued that farmers' ability to adapt to challenges and cope with issues surrounding CA and indeed the DBF lies in their ability to modify, experiment with and re-innovate the novel farming systems according to their social-ecological uniqueness. To better understanding the social-ecological sustainability of the Tiyeni DBF, therefore, this chapter explores how farmers modify, re-innovate, and experiment with various aspects of the DBF and why they do so. The central argument in this chapter is that these on-farm smallholder farmers' trials are part of an integral process of building sustainable cropping systems that are both resilient to internal and external pressures and shocks and can be adapted to suit uniqueness of place in the ever-changing environment.

8.1 Cropping systems as experiments

Content and thematic analysis of interview and group activities datasets reveal that farmers consider their participation in agricultural development programmes as trying out new technologies in order to compare their relevance with their existing or previous farming systems (Figure 8.1 and Appendix 3). In response to the survey question on whether a farmer ever tried practising a different farming system other than their conventional ridge-based cultivation (Appendix 4), over 74% of the current DBF farmers had tried other cropping systems such as no-till, Basin/pit CA, agroforestry, and maize-legume intercropping (Figure 8.1 and Table 8.1).

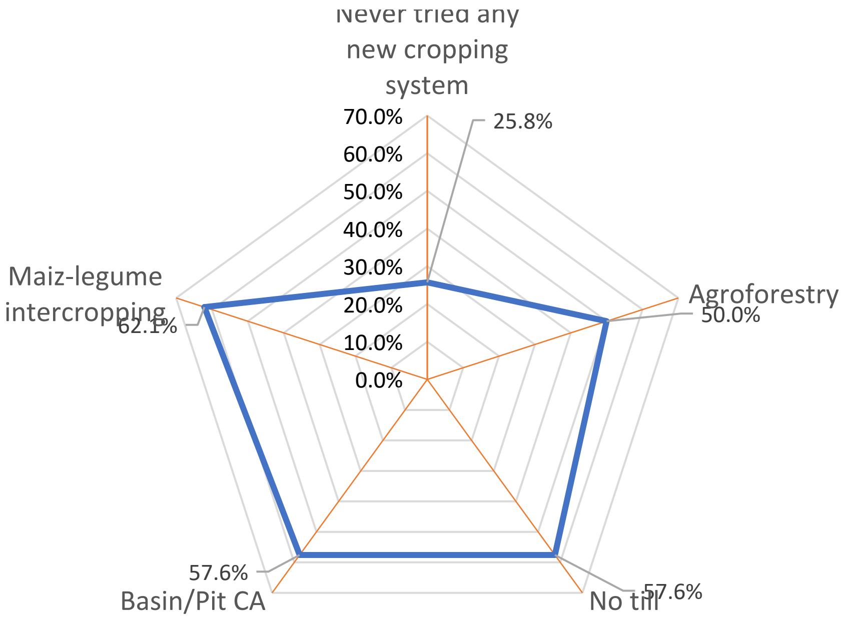


Figure 8.1 Percentage of respondents experimenting with new farming systems.

Table 8.1 Cropping systems as experiments (by site)

Site	Count	Type of a new farming system tried[a]					Total
		No Till	Basin or Pit CA	Agroforestry	Maize - legume intercropping	Tried no new system	
Mtavu	Count	7	7	6	9	3	12
	%	18.4%	18.4%	18.2%	22.0%	17.6%	
Kapata	Count	4	4	4	6	7	15
	%	10.5%	10.5%	12.1%	14.6%	41.2%	
Malaya Nkhata	Count	0	0	0	2	3	5
	%	0.0%	0.0%	0.0%	4.9%	17.6%	
Chikwina	Count	10	10	9	9	1	12
	%	26.3%	26.3%	27.3%	22.0%	5.9%	
Chipapa	Count	8	8	5	7	2	11
	%	21.1%	21.1%	15.2%	17.1%	11.8%	
Jalanthowa	Count	9	9	9	8	1	11
	%	23.7%	23.7%	27.3%	19.5%	5.9%	
Total	Count	38	38	33	41	17	66

Percentages and totals are based on respondents.

a. Dichotomy group tabulated at value 1.

According to these farmers, they had and still do participate in various agricultural development projects (Table 8.1), retaining and modifying some of the useful aspects of the technologies and discarding irrelevant ones (statements by Dunstan and Jacob below). Decisions to retain or discard a farming system or its component is dependent on their own criteria using variables like crop productivity, labour requirements, suitability with local conditions and existing practices, resource endowments of an individual, affordability of external inputs and implements, among others. According to Hockett and Richardson (2016), gender roles play a significant role in choice of a farming system or its components because men and women value agricultural interventions differently.

While women are inclined to enhance household food availability given their societal roles as primary household carers, men on the other hand have a propensity to value those interventions leading to more income (Kerr, 2005; Hockett & Richardson, 2016). Whereas agricultural technology promoters may consider farmer participation as adoption of these farming systems (Kassam et al., 2017; Gondwe, 2018), results show that farmers take these farming technologies as series of experiments they conduct to respond to site-specific social-ecological changes across temporal and spatial scales. The knowledge gained from these experiments, whether actively used or not, is important for farmers because it helps them diversify their options should need for a specific innovation arise, increasing their adaptive capacity for resilience and sustainability of their social-ecological systems.

> *"Since I retired from my bricklaying profession in 1995, I have been involved in numerous agricultural promotional projects such as no-till and pit farming by Total Land Care and agroforestry by LISAP. But I needed to move to deep beds in 2014. Time changes so I also need to try modern technologies to choose which one is better for me. I do not stay in the past. I need to move forward to keep up with changes in rainfall".*
>
> Farmer 4DMJ, (2019)

> *"Deep beds are not the first farming technology we have tried here in Jalanthowa. My wife and I have been involved in many agricultural projects such as the one by Total Land Care where they told us not to till, but to cover our soils with maize stalks and spray our fields with herbicides. This never worked. Now we are trying deep beds to see how different it is from the rest of the technologies we have practised before"?*
>
> Farmer 4JLJ, (2019)

In response to the question 'what makes a successful trial?', farmers cited increased and sustained maize yields as a major variable used to classify an experiment as such. With their traditional CR as a control treatment, the novel crop production system is expected to provide more maize yields to stand the test of time. As Jacob narrates below, poor yield is likely to play a significant role in the decision-making process of a smallholder farmer on whether to continue the trial or not. In the field, it was observed, backed by content and thematic analysis of interviews and group activities, that the location of the DBF plot for some farmers is influenced by the experimental thinking with a hypothesis that the new farming system would be able to halt soil erosion and degradation, improve soil fertility and maize yields as 4LMJ narrated (Section 5.2).

For 2WMM in Mtavu, the DBF worked because it helped him stop soil erosion, reclaim soil fertility and improve crop productivity on his plot when compared to CR. Conversely, Daniel Kondowe in Kapata did not find any benefit of using the DBF, prompting him to revert the plot back to CR for tobacco growing. Lessons learnt in each case influence whether adopt the farming system in its entirety, discard and retain some of its components or abandon it completely. As Daniel narrates, the effectiveness of the DBF in delivering these experimental expectations also depend on an individual farmer's willingness to engage in any of the system's key components, deep tillage and protection of de-compacted soil among others being some of the essential catalysts.

> *"Our experience with no-till was not pleasant. Because we did not till the land, seeds failed to grow properly in addition to lack of a sprayer and access to herbicides. Crop residues on untilled land made it difficult to work the soils, plant*

> *seeds, weeding or apply fertilizers. These are the reasons why my wife and I decided not to repeat no-till…"*
>
> Farmer 4JLJ, (2019)

> *"I have been struggling to contain soil erosion on my plot at the base of the hill. I tried many techniques. The DBF does it better than the previous methods I tried. I have not seen any significant soil losses the past two years I have tried DBF on that plot…"*
>
> Farmer 2WMM, (2019)

> *"…Since I started using beds, I have never seen good yields… I think it failed because I was busy with tobacco to put maize stalks and make and apply manure on the DBF plot as Tiyeni wanted. I know my neighbours got good maize yields than me because they did most of what Tiyeni recommended."*
>
> Farmer 5DKK, (2019)

Abundance of soil fauna, change of soil colour from brown to darkish, and presence and health of some weeds like blackjack (*Bidens pilosa*), whiteweed (*Ageratum conyzoides*), *Ryncheltrum repens*, *Uaparca kirkiana* and wandering jew (*Commelina banghalensis*) are equally important variables that help farmers decide whether their DBF experiments are successful or not. Similarly, presence of plants and weeds like *Brachystegia taxifolia*, *Melinis repens*, and Bristly starbur (*Acanthospermum hispidum*) are common indicators of infertile soils. A farming system that can visually present such changes in soil colour is often seen as a better technology and is more likely to be sustained. Manure application and crop residue retention in DBF (where they are done) were widely cited practices attributed to improving soil fertility and crop productivity.

> *"… A good soil looks darkish in colour, with a balanced amount of clay, sand and silt. The second is observing what grows on that land. Plants like Kachiwanga (bristly starbur) for example can only grow in fertile sandy soils. One of my plots never used to have this weed until I began DBF and manure application".*
>
> Farmer 6CNM, (2019)

> *"… Plants like black-jack, whiteweed, blanketgrass, wandering jew and Indian goosegrass (Eleusine indica) are good indicators of a fertile land. A good growth of these plants tells you how good that soil is, and they can be used to track changes when a new farming technique is used."*
>
> *Farmer 6TNM, (2019)*

> *"The presence of white worms in the soils are a good indicator that that soil is particularly good. In many cases, these white worms are associated with places where there was a cattle kraal and so is very dark in colour and rich in plant nutrients".*
>
> Farmer 2PMM, (2019)

Outcomes of experimenting with the DBF and indeed CA can trigger the need to adapt, modify or omit components of the farming system, leading to series of smaller experiments that test efficacy of individual parts of the technology. Technologies not very suitable for an individual's social-ecological circumstances are discarded (Chinseu et al., 2019) or its most relevant components are retained or adapted. The knowledge gained, however, may be useful to counter future crises and reorganise a farmer's social-ecological system should it be subjected to perturbation like dry spells, droughts, floods among others (Alison & Hobbs, 2004; Darnhofer et al., 2010).

8.2 Adapting and modifying the DBF.

Field observations and interviews showed that about 60% of farmers had tried to change, modify, or omit one or more DBF components (Figure 8.2) and that more men than women altered and adapted the DBF (Table 8.3). In terms of specific DBF aspects, 36% of men modified tillage depth, 33% omitted vetiver while 39% planted crops on contour ridges instead of vetiver or other grass types compared to women who attempted doing the same (Table 8.3). A similar trend is observed in terms of inclusion or exclusion and modification of marker and box ridges (46% men and 33% women). Similarly, 73% of respondents indicated that they had applied one or more of DBF components elsewhere on their farm (Figure 8.3 and Table 8.4).

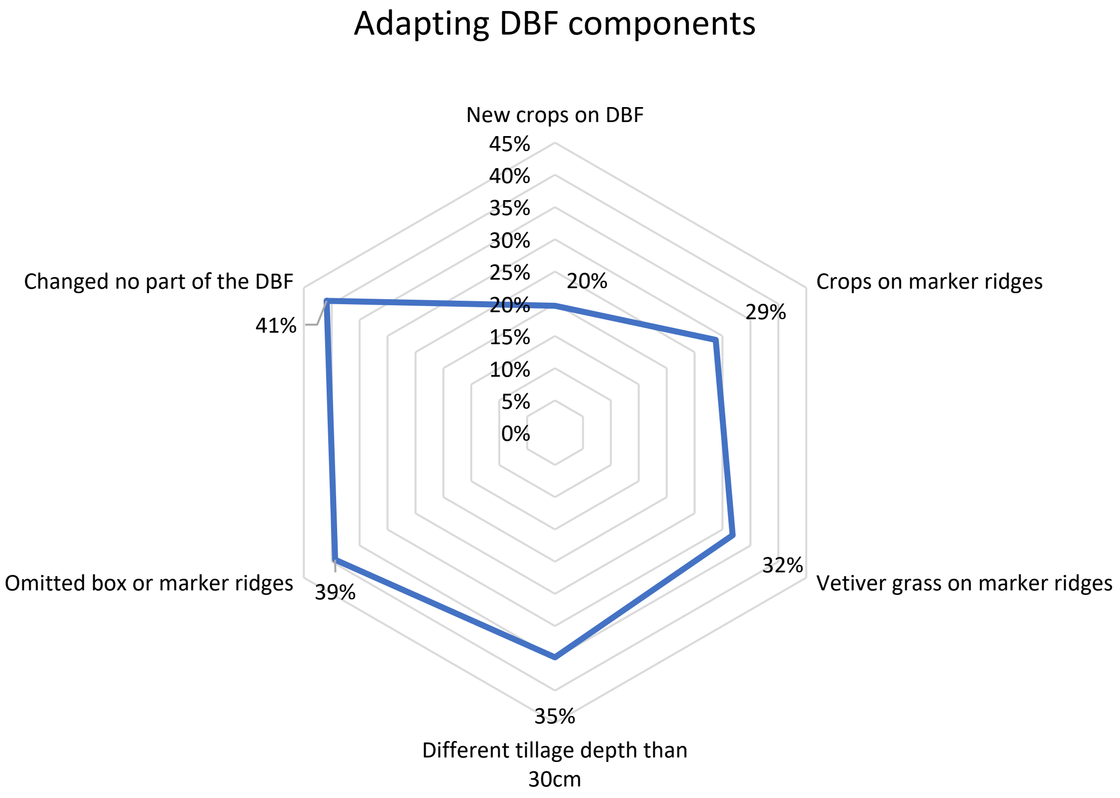


Figure 8.2 Components of the DBF system commonly altered, adapted, or omitted by farmers

Table 8.2 DBF adaptation and modification according to gender.

DBF component		**Gender**		**Total**
		Female	Male	
Tillage depth	Count	11	12	23
	% within Gender	33	36	35
No vetiver	Count	10	11	21
	% within Gender	30	33	32
Crops on marker ridges	Count	6	13	19
	% within Gender	18	39	29
New crops on DBF	Count	3	10	13
	% within Gender	9	30	20
Omitted box/marker ridges	Count	11	15	26
	% within Gender	33	46	39
Changed no part of the DBF	Count	15	12	27
	% within Gender	46	36	41
Total	Count	33	33	66

Percentages and totals are based on respondents for each category and question.

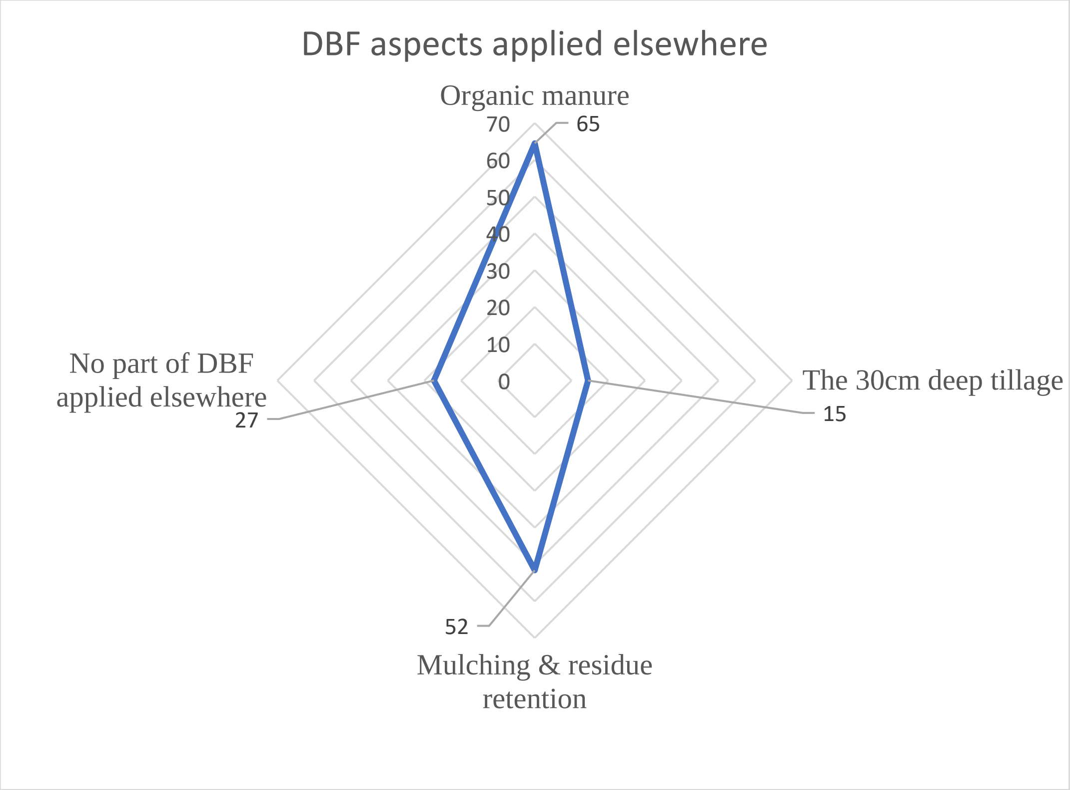


Figure 8.3 Aspects of the DBF farmers applied elsewhere.

Table 8.3 DBF components elsewhere (by site)

Community		DBF components applied elsewhere[a]				
		Organic manure	30cm deep tillage	Mulching & crop residue retention	No part of DBF applied elsewhere	Total
Mtavu	Count	10	5	8	2	12
	%	25.0%	55.6%	25.0%	11.8%	
Kapata	Count	7	0	5	7	14
	%	17.5%	0.0%	15.6%	41.2%	
Thandazga	Count	5	2	3	0	5
	%	12.5%	22.2%	9.4%	0.0%	
Chikwina	Count	7	1	6	3	11
	%	17.5%	11.1%	18.8%	17.6%	
Chipapa	Count	4	0	6	2	9
	%	10.0%	0.0%	18.8%	11.8%	
Jalanthowa	Count	7	1	4	3	11
	%	17.5%	11.1%	12.5%	17.6%	
Total	Count	40	9	32	17	62

Percentages and totals are based on respondents.
a. Dichotomy group tabulated at value 1.

Section 5.3 detailed why some farmers find other DBF elements redundant, unnecessary, or unsuitable in certain social-ecological circumstances. The discussions on box and marker ridges on a flat land or sandy soils in Chapter 5 and Chapter 6 demonstrate this complex situation. While the marker ridge is an important physical barrier to rainwater movement on a sloping land in Chikwina, Kapata and partially Mtavu, for instance, planting vetiver on the same has been highly contested by farmers in Jalanthowa, Chipapa and Malaya Nkhata whose land is on undulating terrain or have sandy soils. Similarly, farmers with limited land size may want to capitalise on every space they have to produce food supplementary such that growing of crops on contour ridges becomes better than erosion control functions of planting vetiver grass (Section 5.3).

8.2.1 Non-recommended crops on DBF

About 20% (Figure 8.3) of farmers introduced new crops onto their DBF plots to observe and compare results against CR. Madalitso Nkhata, for example, found that cultivating cassava (*Manihot esculenta*) on deep beds (Figure 8.4) resulted in its early maturity and better yields relative to those on CR or mounds. Madalitso concluded that the cassava matured early because of the deep tillage since well-tilled land made it easy for crop roots to grow, access nutrients and water unlike on traditional ridges. Along with new crops, he also changed the shape and, size and depth of the beds (Figure 8.4). Given that he never needed to do deep tillage (his land has high sand contents), making deeper and wider beds was an easy task, which also benefited cassava, a tuber crop that needs well drained soils. On the other hand, farmers in Chikwina contested this finding, arguing that early maturity of cassava crop does not necessarily depend on the type or depth of tillage. Rather, it is about the crop varieties. For example, hybrid cassava varieties in Chikwina mature earlier than local ones under the same conditions.

Figure 8.4 Cassava monocropping on modified DBF in Malaya Nkhata.

> *"Out of my own curiosity, I tried growing cassava on deep beds because I thought the crop needs good tillage to thrive. My observation has been that the same variety I used to harvest after two years on ridges now matures in a year. I have tried this twice, but Tiyeni officials do not know about this. They do not want cassava being grown on deep beds, so I do not want to argue against them…"*
>
> Farmer 6MNM, (2019)

Other farmers have also tried growing potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*) and tomatoes (*Solanum lycopersicum*) on deep beds to evaluate the effect of tillage and depth on yields and for diversifying their crop production and income sources. While farmers in Mtavu began growing potatoes and sweet potatoes out of curiosity, Celina Thindwa started planting tomatoes on beds to drain excess water in her plot given that she grew her crops in the rainy season and close to a wetland. In areas where cassava growing is common (Malaya Nkhata and Chikwina), maize-cassava intercropping was also observed (Figure 8.5).

Figure 8.5 Maize-cassava intercropping in 6SNM's field.

> *"I tried growing sweet potatoes on deep beds. The yield was impressive. However, harvesting means that I had to destroy the beds. Reconstructing these beds for the next growing season is not demanding work given that the land is already deep-tilled and marker ridges were still intact."*
>
> Farmer 2HMM, (2019)

Normally, crops that involve digging during harvesting are not recommended on DBF as they destroy the bed structure and compromise their long-term use (Section 5.3). For this reason, farmers who often engage in cultivating these non-recommended crops on deep beds have stated their disinclination to share their new knowledge with others in fear of being corrected (or criticised) by Tiyeni officials. Among the non-recommended crops introduced, cassava and sweet potatoes have often been cited as giving high yields relative to CR. Comparatively, potatoes would only do well where deep tillage and organic manure are done simultaneously. Despite that harvesting of these crops would mean making deep beds yearly, the same farmers have observed that because the land is already tilled to 30cm depth, remaking of these deep beds in the subsequent years is less of a burden than in the first year of DBF implementation.

Previous studies have indicated that farmers have specific preferences for specific crops according to their utility (Kerr et al., 2007; Chibwana et al., 2012; Mhango et al., 2013; Snapp et al., 2019;). Among these include cultural values, consumption and local market, cash crops, food crops and those with medicinal properties (Chibwana et al., 2012; Mhango et al., 2013). By limiting which crops can be grown on DBF or any other cropping system, one does not only limit farmers' ability to diversify their crop production, but also limits these values and farmers' learning through doing. Farmers who feel their favourite crops conflict with the DBF (and/or Tiyeni) get disenfranchised and because learning is also curtailed, the DBF loses its value among such individuals and dis-adoption when Tiyeni is no longer in contact is more likely.

8.2.2 Improved manure and its application elsewhere

Use of chemical fertilizers in Malawi and across SSA remains limited due to exorbitant prices (Vanlauwe & Giller, 2006) thus manure provides poorer households with cheaper alternatives (Otsuka & Kalirajan, 2006; Zant, 2014). Results of content analysis reveal that over 60% of farmers have not only increased the amount of manure they make and apply per year relative to before Tiyeni's manure making trainings, but they have also applied the same to areas other than their DBF plots. Normally, farmers with livestock apply raw animal dung in their vegetable gardens and crops grown in dimbas but manure use in CR is not common except for farmers owning cattle which provide substantial quantities of dung. Having learnt new ways of making manure through Tiyeni DBF trainings, farmers have spoken about significant increase in the use of organic manure on plots other than the DBF like on CR plots besides dimbas.

> *"Many of us used to apply raw animal manure in our dimbas. Pig manure is very strong and can easily destroy crops when applied raw. Now with manure making*

> *trainings from JOCA and Tiyeni, I make more and better manure and apply it in both DBF, ridges and the dimba without having to outsource the raw animal dung".*
>
> Farmer 2MMM, (2019)

> *"The heavy use of manure is the other thing I have learned. I use manure in my field more than the past. That's why you have seen my boys and wife carrying animal dung from cattle and goats for making compost manure (pit manure)"*
>
> Farmer 2KMM, (2019)

Farmers have spoken about applying this type of manure in their dimbas and sometimes CR fields to improve their crop productivity as Farmer 2MMM and Farmer 2KMM narrated. Besides increased levels of manure application, extending its use to plots other than the DBF is an important farming system resilience and adaptation strategy for certain groups of farmers. For example, the elderly who cannot extend their DBF plots due to limited labour availability and the physique involved in deep tillage, new knowledge about manure and its subsequent application on CR can significantly enhance their crop productivity and hence food security and improved wellbeing. Experiences from this sort of experimentation can easily be noticed by non-DBF farmers who may also adopt such strategies for their own farms, extending DBF manure making beyond Tiyeni clubs and beyond community networks of farmers (Chapter 7).

Coupled with low efficacy (Vanlauwe et al., 2010; Zant, 2014) that demands large quantities of manure per unit area, inadvertent labour demands involved in making and applying most types of manure make it unattractive for some farmers. Indeed, farmers have expressed uncertainty about mixing their inorganic fertilizer with manure as Tiyeni recommends because of the perception that manure does not work or takes longer to effect change in crop productivity (Section 6.3). To reduce labour demands in making and applying manure and to improve its effectiveness, Chikwina farmers formed Kwanjana club with the intention of blending their collective manure making knowledge to formulate Kwanjana manure.

According to Chikwina farmers, Kwanjana manure is as effective as inorganic fertilizers and takes little time to make, transport, and apply; thus, cutting on labour demands and reducing need for inorganic fertilizers while improving crop productivity. Whereas other farmers may give up on manure making and lose out on its benefits, Chikwina farmers adapted what they were taught to make better organic fertilizers. Even where prices of inorganic fertilizers drastically change, such farmers would be least affected as they have better alternatives. Moreover, manure has multiple benefits of helping conserve soil water, boost microbial activities, soil porosity and fertility improvements (Zant, 2014; Shaxson et al., 2014). Granted its effectiveness and ease of making and applying it, more farmers may adopt Kwanjana, making their farming systems resilient and sustainable when other farmers face the unforgiving impacts of rising prices of fertilizers, droughts and dry spells and soil fertility degradation. Where functional local institutions and healthy farmer social networks exist (Chapter 7), such innovations can help both DBF and non-DBF farmers beyond Chikwina to build more resilient and sustainable cropping systems and agricultural-based livelihoods.

> *"I do not make manure on my own. We do it as Kwanjana group. The manure Tiyeni taught us takes more time and effort to make and is not as effective as inorganic fertilizer. Our group improved on that and combined Tiyeni trainings with others we have had before to make better manure we call Kwanjana. We still use locally found materials to make it, but it's much better."*
>
> Farmer 3DMC, (2019)

> *"…I use Kwanjana manure for my DBF and other purposes. We make it ourselves and it is better than what we have been taught by NGOs. A small amount is enough to cover a large plot size just like inorganic fertilizers. It's not exactly like inorganic fertilizer, but it's better than the rest of organic manure I have made before."*
>
> Farmer 3EMC, (2019)

8.2.3 Use of deep tillage elsewhere

Based on their long-term observations of what happens when land is tilled to certain depths, participants mentioned that they have also been applying deep tillage on plots other than DBF. According to Shadreck and Thomas, deep tillage and making of beds began long before Tiyeni formally introduced the DBF in Malaya Nkhata. According to Thomas below, he began deep tilling in the hope that it would lessen weed growth by burying their seeds under the soil while also improving on crop rooting depth in his dimba. Farmers like Kenneth Mseteka decided to try deep tilling their dimba for the growing of garlic (*Allium sativum*), beans (*Phaseolus vulgaris*) and onions (*Allium cepa*).

> *"I began doing deep tillage and making of beds before Tiyeni came to us to train us. My aim for tilling and making beds in the dimba was to help me retain moisture and improve depth of crop roots. What Tiyeni added were the specifications, especially measurements like tillage depth and bed sizes, box, and marker ridges"*
>
> Farmer 6SNM, (2019)

> "*When Tiyeni came here, I was already doing beds. All I learnt from Tiyeni were the measurement standards. This idea came to me by itself because I thought if I could dig and make the planting basin flat, water could be harvested and improve water infiltration. This trial proved worthwhile when Tiyeni brought its DBF here."*
>
> Farmer 6TNM, (2019)

> *"Because of how well cassava did on a marker ridge, I thought to try deep tillage in the dimba for garlic and onions. For the past two years, I have been doing the Tiyeni crop spacing in the dimba as well. I have noticed that crops are doing really well than the old way".*
>
> Farmer 2KMM, (2019)

While trends show farmers dis-adopting CA practices (Chinseu et al., 2019), this research suggests that knowledge gained through these promotion projects is accumulated and provide precedence and familiarity for newly introduced technologies. The knowledge, though undocumented, still stays on and can be recalled later when required as a fall-back strategy in the process of mitigating and adapting to food production challenges (adaptive learning). The application of deep tillage elsewhere provides important learning avenues in that farmers who cannot see its value can appreciate its importance elsewhere and help them retain or improve on it. For example, deep tillage in Malaya Nkhata is needless for rainfed agriculture given the area's high sand contents. For farmers who have tried applying the practice to dimbas, however, deep tillage provides important benefits such as weed growth suppression, water level control (both drainage in high water level conditions and moisture conservation in drier areas), improve crop rooting and consequently improved crop productivity. While not being DBF plots per se, trying a DBF component elsewhere can enhance farmers' adaptive capacity, contributing to farm system resilience and sustainability.

8.3 Other experiments

In addition to experiments linked to certain cropping systems above, other trials have been identified (Figure 8.6). All participants (93%) tried growing new varieties of the same crops they had been growing for the past decade. Correspondingly, 84% have tried growing a new crop, about 47% mentioned that they tried changing plant spacing for different crops, while only 9% have tried selling green maize instead of dry grains. In terms of gender, women were more inclined to try new crops (90.6%) and new varieties (100%) than men (Table 8.5). Conversely, more men (16.1%) sold their maize crop while still green unlike women (3.1%).

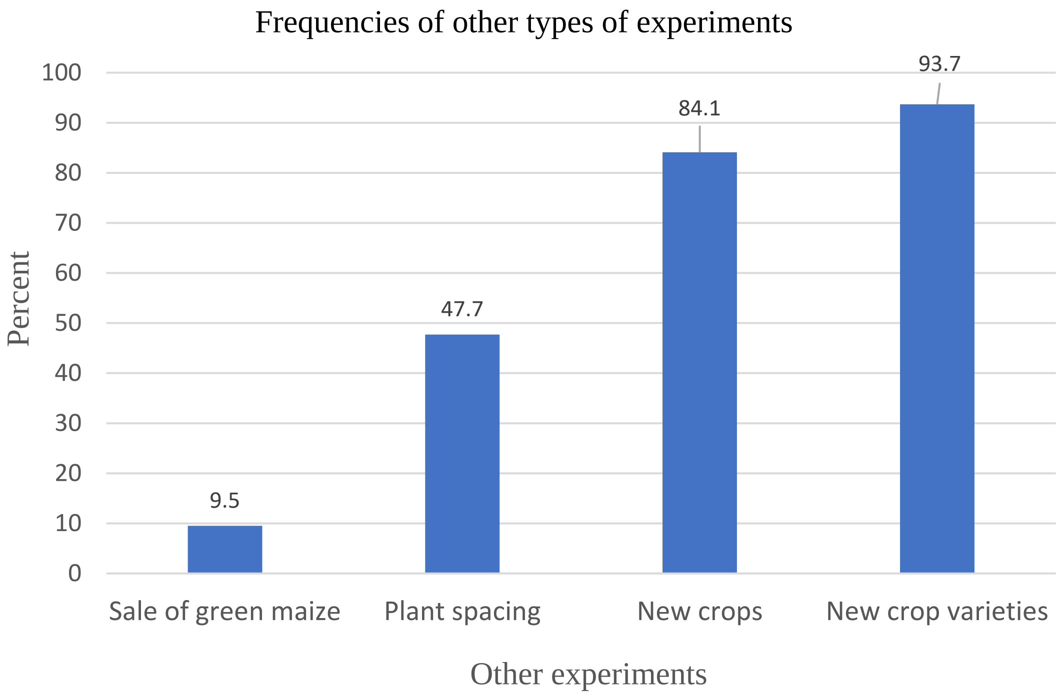


Figure 8.6 Other types of experiments among smallholder farmers

Notwithstanding the importance of maintaining DBF's structural stability for long-term use, trying out new crops can provide farmers with new experiences on how best to utilise the technology's potential to their advantage. Coupled with the freedom to use any crop varieties available (besides hybrids), this can provide solutions to DBF technology ownership conundrum and enhance farmers' ability to adapt the system as a vehicle towards resilient and sustainable social-ecological systems. Granted women's vulnerability to climate change impacts on household food production and availability in SSA (Jost et al., 2016; Rao et a., 2017), their ability to adapt their cropping systems through crop diversification coupled with DBF's potential to increase crop productivity can significantly improve household food security, reduce their vulnerability, and enhance resilience and sustainability of their social-ecological systems.

Table 8.4 Other experiments according to gender

Other experiments		**Gender**		**Total**
		Female	**Male**	
New crops	Count	29	24	53
	% within Gender	91	77	80
New varieties	Count	32	27	59
	% within Gender	100	87	89
Plant spacing	Count	13	17	30
	% within Gender	41	55	45
Selling green maize	Count	1	5	6
	% within Gender	3	16	9
Total	Count	32	31	63

Percentages and totals are based on respondents.

Farmers like Madalitso Nkhata and Dunstan Mkandawire who are both closer to towns (Mzuzu and Ekwendeni) tried selling green maize to compare earnings with sales from dry crop. Realising high profits from their trial, about 3/4 of their crop is sold whilst fresh. Furthermore, Dunstan uses his DBF plot for green maize, which, according to him, improved his income from this enterprise. Much as this enterprise can only work for farmers near towns, it has the potential to significantly enhance and improve investments returns from the DBF. This increased income enables them to invest in hybrid seeds, herbicides, inorganic fertilizers for subsequent growing seasons as well as livestock like pigs, goats, and cattle. Over a certain period of time, this enterprise has the potential to enhance resilience and sustainability of smallholder farmers' livelihoods. For poorer farmers struggling with food shortages, this may not be ideal even where they are able to access markets for green maize given their limited production capacity.

> *"When I retired in 1995, I wanted to try and find the most profitable crop and best period to sell that crop at the highest price. I tried many crops, but it turned out that green maize is very lucrative. Even now, I have plots for selling green maize and another one for dry harvest. About one acre is grown with the first rains so I know it's only me with mature green maize."*
>
> Farmer 4DMJ, (2019)

> *"People said I was crazy when I began selling green maize before harvesting. I had observed that I earn more money selling my crop this way than dry grain. With the money from the sales, I can buy dry grain for my food at a cheaper price from the same farmers who think I am crazy. Not many farmers can see this, but it's a profitable business for smallholder farmers like me."*
>
> Farmer 6MNM, (2019)

8.4 Drivers of experimentation: why experiment?

Content analysis of interviews and group discussions revealed that smallholder farmers experiment as a response to some observed social-ecological changes like erratic rainfall, soil erosion and fertility degradation, and economic challenges, in anticipation of acceleration of the latter, a combination of these two or because of being fascinated by a certain set of agricultural practices. Figure 8.7 shows that most farmers engaged in various trials to diversify their income and food sources (81%), pushed by prohibitive costs of inorganic inputs, soil erosion and declining soil fertility and changes in rainfall amounts and unreliability due to climate variability and change (72%, 70% and 49% respectively). About 53% of those who tried something new on their farm reported that their trials were initiated due to their curiosity, either by observing what other farmers did, from listening to local radio stations, existing agricultural projects in their communities or their perpetual need to try something new. For the majority of these, their experiments were derived from their past knowledge of numerous promotional projects from which they would draw a certain set of information and combine the same with knowledge from elsewhere to perform a trial and evaluate it against their baseline (CR) (Kwanjana manure is a product of this process).

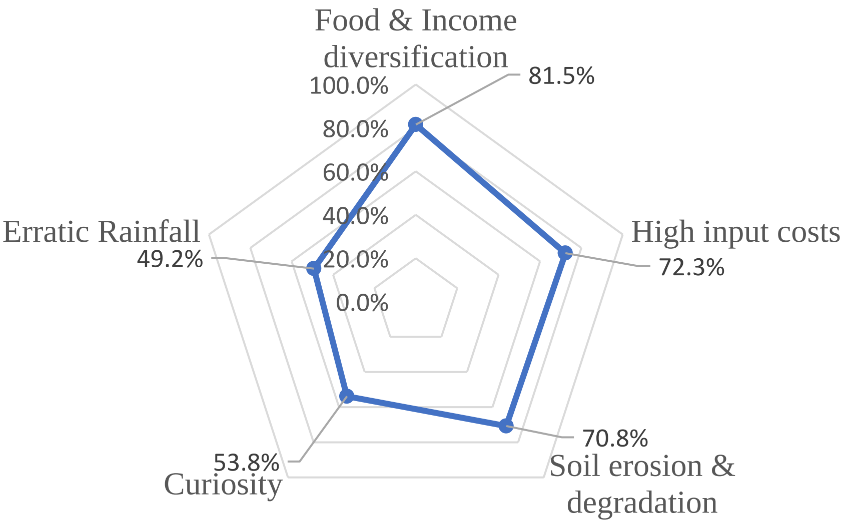


Figure 8.7 Drivers of experimentation among smallholder farmers

The need to increase and diversify food and income sources has been found to be the major reason farmers tend to engage in on-farm trials in the face of changing rainfall regimes and continued soil fertility degradation (Chibwana et al., 2012; Njoloma et al., 2016) and the basis for CA in SSA (Hobbs, 2007; Steward et al., 2018). Group discussions and interviews indicated that farmers have noticed decreased crop yields owing to the unreliability of rainfall in Jalanthowa, Chipapa and Mtavu, over used land (Jalanthowa, Chipapa), and soil fertility degradation due to persistent soil erosion (Chikwina, Kapata, Mtavu and Jalanthowa). Conversely, the prices of buying inorganic fertilizers have been on the rise for the past two decades (Vanluawe et al., 2012). These rising costs make it difficult for resource-poor smallholders to access resources, pushing them to innovate by trying out alternatives like locally made manure.

The number of farmers involved in experimentation processes confirms the discussions and arguments that externally imposed agricultural technologies lack a focus on site-specificity (Andersson & D’Souza, 2014; Giller et al., 2015). Trying out different tillage systems and other associated practices are attempts to reshape these technologies into a close-to-ideal set of practices that are specifically adapted to their needs. Participants who indicated that their motivation was their own curiosity often linked their work to external sources.

> *"I had seen farmers retaining maize stalks on their plots in Lilongwe before I retired in 2002. When I came home, I was given land with poor soil fertility. I then remembered that I could make it better by incorporating crop residues and weeds in the soil. This worked after about six years of consistent practise."*
>
> Farmer 2KMM, (2019)

> *"I was the first one to see deep beds when I travelled to see my friend. I got curious and I told my colleagues about it and later a club was formed. My friends often think I am crazy because I tend to try new farming techniques novel to what we know in our community. Others work. Others fail. But I learn from both".*
>
> Farmer 6MNM, (2019)

Table 8.5 Drivers of experimentation among women and men

Drivers of experimentation		Gender		Total
		Female	Male	
Curiosity	Count	12	23	35
	% within Gender	38%	70%	
Erratic rainfall	Count	13	19	32
	% within Gender	41%	58%	
High input costs	Count	23	24	47
	% within Gender	72%	73%	
Food & income diversification	Count	30	23	53
	% within Gender	94%	70%	
Soil erosion & degradation	Count	24	22	46
	% within Gender	75%	67%	
Total	Count	32	33	65

Percentages and totals are based on respondents.

A look at a gender perspective of the drivers of experimentation, Table 8.6 shows that most women who are actively involved in experimentation do so to diversify their food and income sources (94%) followed by the need to reduce soil erosion and halt soil degradation (75%) and high input costs (71%). On the lower end, curiosity among women was the least reason for experimenting with the DBF or its components (38%) while only 41% of them engaged in experimentation because of the apparent erratic rainfall trends for the past two decades. Given their role responsible for taking care of the family in several ways such as preparing meals, a lack of food in the household is primarily a woman's problem (Kerr, 2005; Hockett & Richardson, 2016). For men, high input costs (73%) were the major factor, although the rest of the drivers had an equal influence on their propensity to experiment, suggesting that their need to adapt some components of the DBF was influenced by high costs of crop production and need to improve income earnings.

8.5 Linking farmer experiments to DBF sustainability

In itself, the DBF is an experiment among these farmers that forms farmers' continuous adaptive learning involving making observations and comparisons relative to CR and other previous CA practices like no-till. By participating in various agricultural development projects (DBF, No-till, wetland cultivation etc.), farmers generate, refine, retain, and accumulate site-specific knowledge about multiple farming systems and their individual components which evolve over time and place (Chambers et al., 1989; Reid et al., 2007). While not all knowledge will be used at the same time and same social-ecological conditions, this accumulated knowledge forms an important pool of options for various groups of farmers to tap from when faced with social-ecological challenges like dry spells, fluctuations in input prices, poor health, and loss of reliable income sources (Solvic, 2010; Sinclair et al., 2014; Kaluzi et al., 2017).

Farmers' ability to cope with change, recover from it, maintain their agricultural systems productivity and livelihoods in the face of looming challenges by experimenting with the DBF forms essential building blocks for site-specific resilience and sustainability of both the technology and farmers' social-ecological system. A smallholder farmer's adaptive capacity requires that the learning process be continuous and iterative in nature to be able to deal with site-specific social-ecological changes (Kanyama-Phiri et al., 1998; Smit & Wandel, 2006; Nelson et al., 2007; Brabowski et al., 2018; Snapp et al., 2019). In DBF, this is achieved by farmers involved in various DBF adaptation activities.

Figure 8.8 summarises commonly adapted and modified DBF components among smallholder farmers as presented in this Chapter. Besides the DBF being an experiment in itself, farmers have also tried new crops, improved on Tiyeni way of making manure, changed tillage depth for various reasons, omitted vetiver, box or contour ridges, or tried using DBF components to accomplish some objectives on non-DBF plots. Depending on a farmer's social-ecological conditions, outcomes of this experimental process provide basis for decision making on whether to sustain or abandon a practice or simply discard/retain its elements. For farmers grappling with soil erosion, for instance, making of contour and box ridges, planting of vetiver grasses and crop residue retention may be solutions for their problems even on CR plots. On the other hand, poorer farmers in undulating areas with poor soil fertility appear to value organic manure application than those who can easily afford inorganic fertilizers. Results from each of these trials can also trigger another set of experiments. For example, improved manure may intrigue some farmers to increase their DBF plot sizes or have time to retain maize stalks on beds.

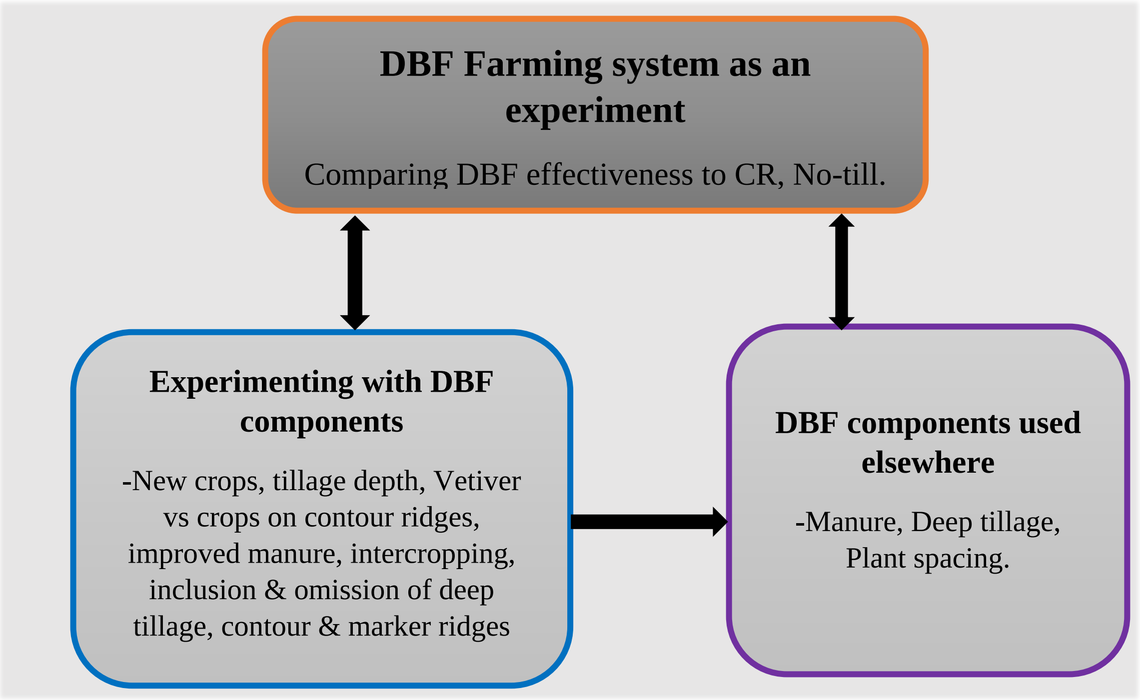


Figure 8.8 Illustrating DBF adaptation through experimentation.

In the context of DBF, success of this system is assessed by how much effort, fertilizer, and manure need to be invested, against crop yields and soil fertility improvements, erosion reduction and water harvesting benefits. However, improvement or lack of it in any one of these indicators does not necessarily mean a farmer will adopt it or discontinue the trial. Schön (1983) and Nitsch (1990) argued that, because smallholder farmer experimentation is an iterative and context-specific phenomenon, the decision to continue or halt a trial depends on a plethora of dynamic internal and external factors. Other indicators and personal circumstances such as good health, livestock availability, availability of alternatives to a set of interventions among others equally count. For example, a widow raising orphans may find use of manure on deep beds rewarding, but illness may cause her to temporarily give up deep tillage and pit manure making given the lack of labour (see Chapter 5).

Experimentation, whether intentionally done or not, provides a rich ground for smallholder farmers' redesigning and modification of various cropping systems into a blended form that can serve a context-specific purpose (Figure 8.9). Because the latter is a complex mix of most techniques a farmer has on their go-to list, a gradual transformation of what a farmer practices on their farm occurs as they continuously respond and adapt to rising challenges, a core idea of a sustainable system (Berkes et al., 2004; Walker & Cooper, 2011). Where a farmer engages in this process, they use their accumulated knowledge to make necessary changes to their farming system without having to depend on external supervision and interventions. Undoubtedly, this can only be realised when technology ownership is devolved onto the local level where a farmer is able to experiment, modify, test and share their findings without the fear of being corrected and where agricultural development partners are able to recognise farmers as co-researchers and innovators (Rhoades & Bebbington, 1995; Chambers, 1998; Kanyama-Phiri et al., 1998; Snapp et al., 2019).

8.5.1 The DBF experimentation and adaptation conceptual model

Using results in this chapter through the lens of the Adaptive Cycle (Chapter 3), Figure 8.10 is a conceptual model illustrating the role and place of farmer experimentation in the process of building resilient and sustainable agricultural-based livelihoods. The model begins with the interactions between farmers' existing agricultural practices, their unique social-ecological knowledge and the influence of emerging shocks and pressures that necessitate the need to adapt and innovate the existing knowledge to cope, protect or enhance their social-ecological systems. Chief among the emerging shocks and pressures include perceptions of a changing climate as in the form of erratic rainfall patterns (Ngongondo et al., 2011; Vincent et al., 2014; Michler et al., 2019) and soil fertility degradation and decreasing crop productivity (Njoloma et al., 2016; Mloza-Banda et al., 2016).

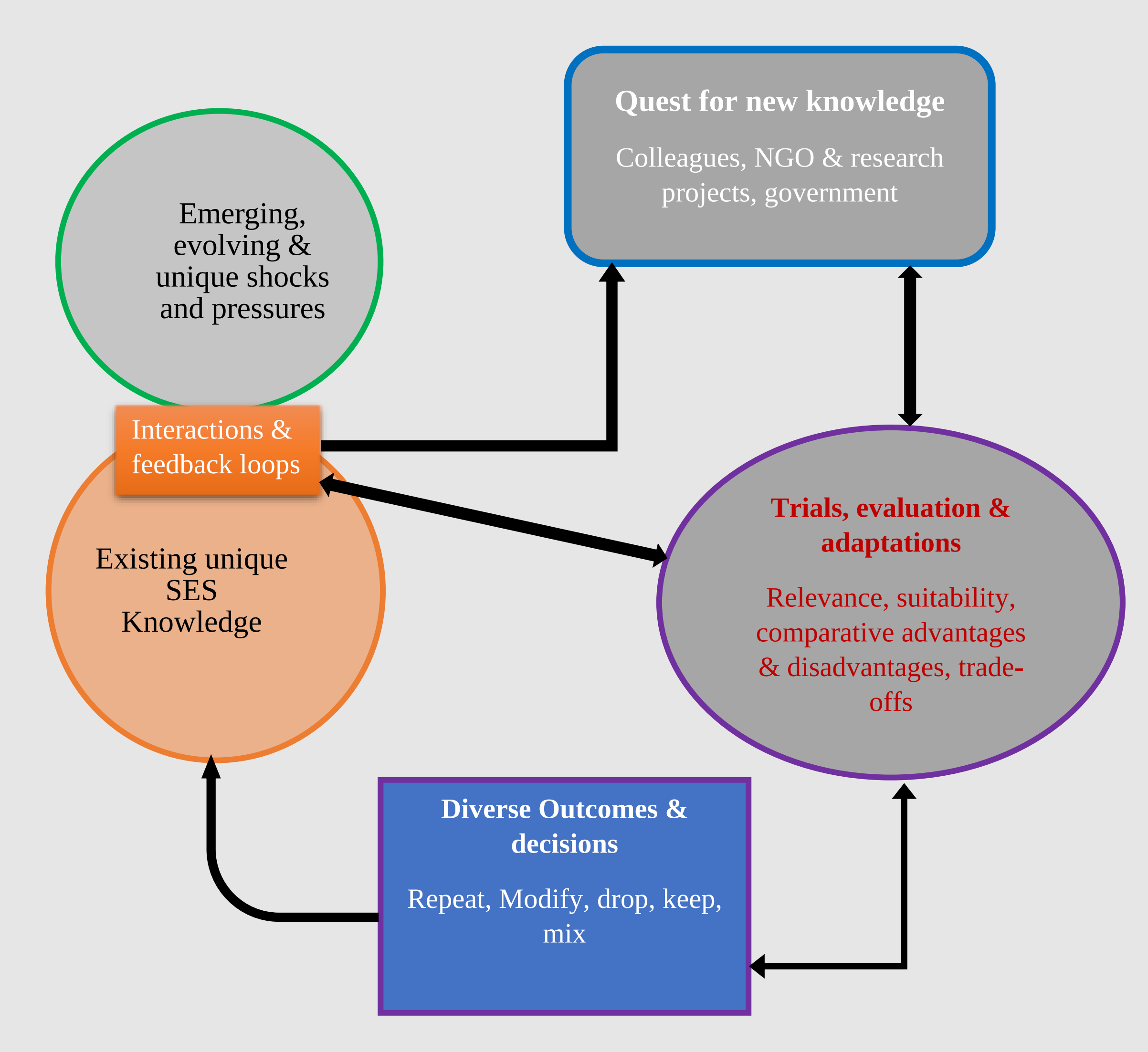


Figure 8.9 DBF farmer experimentation conceptual model (start from Emerging shocks)

Consequently, farmers begin searching for improved crop production technologies that are relevant and appropriate to their unique situations (Quest for new knowledge). These may be from participating in NGO agricultural or livelihood projects, consulting and observing colleagues or asking for help from government extensionists (AEDOs or AEDCs) (Khaila et al., 2015; Ragasa & Niu, 2017). This is where Tiyeni and other agencies come in to provide farmers with alternative approaches to enhancing existing agricultural knowledge and practices. Here, the DBF is simply one of the many options any one farmer has as they strategize to improve and adapt their existing knowledge and practices.

Depending on the uniqueness of an individual's social-ecological conditions, findings in this chapter suggest that despite the DBF being promoted as a discrete package of practices, farmers break this down into individual components for evaluation, trial and/or modification. For example, farmers in areas with sandy soils may find deep tillage or box ridges superfluous and onerous but may value residue retention or manure application that helps them improve the soil's fertility status. Similarly, areas with highly erodible soils and steep slopes will find box ridges, contour ridges and planting of vetiver grass vital in their drive to reduce soil degradation through soil erosion by water. In the same vein, farmers who feel making manure is unnecessarily labour demanding may try alternatives or improve on it by combining their accumulated manure making knowledge. Undoubtedly, the experimentation stage yields numerous outcomes from which the farmer chooses from. It is therefore pointless to advance a rigid blueprint of what the correct DBF must be or to enforce the implementation of every component of the system among farmers with unique social-ecological conditions.

8.5.3 Scenarios that capture DBF experimentation

Steep slopes and high rainfall areas (Chikwina and Kapata): These areas are characterised by steep slopes and highly erodible soils that leave farmers vulnerable to continued soil fertility degradation. This is exacerbated by high rainfall durations and intensities. In such areas, contour and box ridges, vetiver as reinforcements of contour ridges, crop residue retention and manure application help contain these challenges. Given differences in crop preferences relative to areas in Mzimba district, farmers in these communities are also more likely to engage in growing new crops on DBF (cassava, potatoes, sweet potatoes, peas etc.) and application of some of DBF's physical features on plots other than DBF (deep tillage for example). For Chikwina, locating a DBF plot to a suitable land may be difficult under rigid recommendations of what crops to grow, forcing some farmers to either locate their DBF plots in unsuitable wetlands or abandon the technology altogether. The soil erosion control benefits of the DBF in these places has multiple results in that it also prevents degradation of essential wetlands that complement rainfed agriculture. Consequently, farmers in these places are likely to modify and adapt the 30cm deep tillage, contour and box ridges, vetiver grass on contour ridges, crop residue retention and manure making and application. While it is unlikely to retain all DBF components, farmers in these areas may adapt these aspects of the DBF for use on their cassava and wetland plots.

Steep slopes, low and unreliable rainfall (Mtavu): While the area is less steep than Chikwina and Kapata, its location between the hills combined with erodible soils and high population density leave these farmers vulnerable to high levels of soil erosion, consequent fertility degradation and declining crop productivity. Unreliable rainfall patterns have had devastating impacts on maze-based rainfed agriculture such that most of these farmers constantly search for solutions to halt soil degradation and destruction of their wetlands. Consequently, DBF's components that provide solutions to these challenges such as improved rainwater infiltration, reduced soil erosion and manure use are commonly tried and adapted to fit any of the above social-ecological conditions. Adaptation of box ridges, deep tillage, plant spacing and manure making are important for building resilient agricultural system in this place.

Limited land holding sizes is another critical factor that makes some farmers try growing crops on contour ridges instead of vetiver or introducing intercropping like cassava-maize-beans as opposed to Tiyeni's recommendations as strategies to increase and diversify food availability by maximising returns from their limited land. This is often the case with individuals who spent most of their time away from their communities or those moving from their original villages to ask for land to settle and establish themselves in another. Although its critical role in DBF and sustainable agricultural systems, crop residue retention is problematic in places like this because of roaming livestock owing to high population density concentrated in one small area.

Undulating terrain, sandy soils, and average and unreliable rainfall areas (Jalanthowa, Chipapa and Malaya Nkhata): Farmers in places relatively flat may find contour and box ridges, and vetiver planting less useful than those in Chikwina. Because the land is less susceptible to erosion, sizes and distance between contour ridges and box ridges differ. Moreover, some farmers observed that even without these physical features, deep tillage and large surface sizes of the beds accomplish soil erosion control functions required on their plot. For farmers in these situations, they can save time and effort making contour and box ridges and planting of vetiver and invest their resources in alternative livelihood activities like dimba cultivation, small-scale businesses etc. Coupled with plot size reduction effects, vetiver on contour ridges is commonly discarded and crops are preferred. For poor farmers unable to afford inorganic fertilizers to replenish lost soil nutrients due to long-term soil fertility degradation find use of manure important. However, labour and livestock challenges also determine the extent to which such farmers can benefit from these benefits, much like the case of crop residue retention.

In Malaya Nkhata, high sand contents, flat terrain and reliable rainfall make deep tillage, contour and box ridges and vetiver unnecessary, which explains why these DBF components are often omitted on rainfed plots. However, fertility improving components of the DBF including manure and crop residue retention provide important incentives towards improving soil fertility. Moreover, deep tillage (there is no hardpan to break here!) and box ridges help them conserve moisture in their dimbas. With prior experience with these two and the importance of dimbas in this area, DBF, regardless of being less useful on rainfed plots, remains relevant for winter cropping. A rigid promotion of all DBF components in such cases is not only retrogressive and less helpful, but also makes farmers lose focus of what aspects of the system can make a difference on their farms. These simple considerations may be key making sure that the DBF (and CA) adapt and respond to prevailing social-ecological conditions, are suitable and appropriate and that they can be easily integrated within resource poor smallholder farmers' existing farming systems (Gunderson & Holling, 2002; Giller et al., 2009; Andersson & D'Souza, 2014; McGinnis & Ostrom, 2014; Giller et al., 2015)

Places with limited land holding sizes, degraded soil fertility due to land overuse: Places like Jalanthowa, Chipapa and Mtavu also showed high levels of soil compaction and associated soil fertility degradation due to compounding interactions between limited holding sizes and continuous hand hoe tillage. Despite labour involved in deep tillage, those who tried this component of the DBF observed significant improvements in soil fertility and crop growth. Learning about deep tillage, manure application and crop residue retention make essential changes to farmers production systems who often observed that applying these DBF components to their CR plots can also bring similar positive impacts on soil de-compaction, improved rainwater infiltration, and manure application benefits. Whether farmers continue with the DBF as a package or not, important lessons learned from practising it remain valuable. Depending on a farmer's specific needs, any of these DBF components can be utilised in CR or winter cropping (dimba), which contributes to farmers' progressive adaptation and resilience of their farming systems.

Female-headed and the poorest households: In terms of socio-economic sense, the poorest farmers, female-headed households, and the elderly may find themselves under the jaws of unaffordable agricultural inputs (hybrid seeds, inorganic fertilizers) combined with impacts of climate variability on rainfall and labour shortages. Combination of DBF components that help them produce food without inorganic fertilizers like manure and deep tillage, box and contour ridges that improve water infiltration and reduce soil erosion and degradation are more likely to adapted and applied beyond the DBF plot among these people. While these components are obviously important, labour challenges may complicate and limit poor farmers' ability to maximise any of their potentials, but their impact on their farm system resilience cannot be written off.

8.6 Chapter conclusion

This chapter has demonstrated the vital role of smallholder farmers in building localised and site-specific resilient cropping systems through experimenting with the DBF and its components. More generally, the practice and involvement of smallholder farmers in DBF is an experiment in its entirety. Findings suggest that smallholder farmers engage in and experiment with the DBF as they search for specific solutions to specific social-ecological challenges depending on place and an individual's socio-economic characteristics. For farmers in Chikwina, Kapata and partly Mtavu, constant search for superior farming system that can halt soil erosion and degradation in combination with need to improve crop productivity for income (Chikwina) and food security (Kapata, Mtavu, Chipapa and Jalanthowa) make DBF water conservation functions essential to adapting existing farming systems and enhancing their resilience. Deep tillage, contour and box ridges, vetiver grass, crop residue retention and manure application form essential DBF interventions are all important for such farmers.

Depending on outcomes or observations per individual, DBF components are also applied to non-DBF plots, spreading the benefits that accrue from the farming system and as a way to enhance other aspects of an individual’s farming system. Examples of this include the use of various deep tillage depths in dimbas, for growing of new crops like cassava, or introduction of new crop combinations off Tiyeni’s recommended list. Similarly, challenges associated with each of the DBF components also trigger farmers to modify and re-innovate some of its components. Increased labour requirements and ineffectiveness of manure, for instance, led to Chikwina farmers to re-innovate and formulate Kwanjana manure.

Conversely, in relative flat areas with high population, small land holding sizes and generally degraded soil fertility, deep tillage and manure application appear to be paramount to resolving their challenges. Besides topography and perception of climate variability, soil types and productivity also influence which aspects of the DBF is used and adapted. For instance, deep tillage, contour, and box ridges are rendered redundant for some farmers in the sandy soils of Malaya Nkhata. However, most of these farmers use manure and crop residue retention as strategies to improve fertility of their soil for growing of crops like maize. As they practise and observe farm system dynamics due to introduction of the DBF, smallholder farmers refine their DBF knowledge according to their individual contexts, make decisions on what aspects of the system are important and which ones are not. Collectively, the DBF becomes part of the community’s knowledge pool that can potentially help them cope with perturbations, improve farm system resilience, and enhance their social-ecological sustainability.

The prescriptive and top-down DBF approach coupled with influence of handouts can stifle farmers ability to evaluate and experiment with the DBF hence limiting outcomes and options to choose from. In trying to implement Tiyeni’s blueprint of what ‘correct’ DBF is, smallholder farmers’ ability to independently evaluate, try and adapt the DBF and its individual components according to their unique social-ecological conditions is effectively restricted. The sustainability of Tiyeni’s DBF is therefore dependent on Tiyeni’s ability and willingness to allow deviations and opportunities for site-specific adaptation so farmers can separately evaluate, experiment with, and modify the technology according to their site-specific needs.

Chapter 9

The social-ecological sustainability of the Tiyeni DBF system

Chapter overview

Using the social-ecological systems approach (SES), the preceding four chapters have revealed the complex nature of the interactions among the DBF system components, site-specific environmental characteristics, farmers' livelihoods, and their capacity for adaptation through social connections and on-farm experiments. This chapter draws on these four chapters and their key findings to model the various scenarios and combinations of variables and their outcomes that help provide better understanding of complex interactions and feedback loops among the four key aspects of the DBF model presented in Chapter 3 and reproduced below as Figure 9.1. Section 9.1 discusses the DBF's SESs model according as established by the previous chapters, encapsulating the important combinations of variables and their outcomes. Based on this model, Section 9.2 provides an assessment of key facilitators of sustainability of the DBF and an account of how extension approaches can enable or hinder sustainability to inform future practice and help build the process of sustainability from the onset of agricultural development projects among NGOs, research organisations and government departments.

9.1 Social-ecological models of the DBF

One major challenge in CA for decades has been the failure to recognise how site-specific social-ecological conditions influence and impact on the usefulness, suitability, and effectiveness of practices such as no-till (Tittonell & Giller, 2011; Andersson & D'Souza, 2014; Giller et al., 2015). Coupled with the need to provide evidence of CA's effectiveness to improve adoption rates across the SSA, Section 2.4.1 demonstrated that this led to the one-size-fits-all technology transfer based on experiences from large-scale commercial farms elsewhere (Kassam et al., 2009; Ngwira et al., 2014; Asfaw et al., 2018). Consequently, CA's performance has been far below expectations among smallholder farmers across SSA (Giller et al., 2009; Guto et al., 2011; Pannell et al., 2014; Baudron et al., 2015; Njoloma et al., 2016; Steward et al., 2018). Besides slow adoption of the CA (Giller et al., 2009; Kassam et al., 2017), evidence of dis-adoption has also been widely acknowledged (Grabowski & Kerr, 2014; Chinseu et al., 2019). Based on key findings from the previous chapters, this section provides synthesis of how site-specific social-ecological conditions in CA practice influence and impact on the other and the various outcomes of such interactions and feedback loops using the DBF as an example.

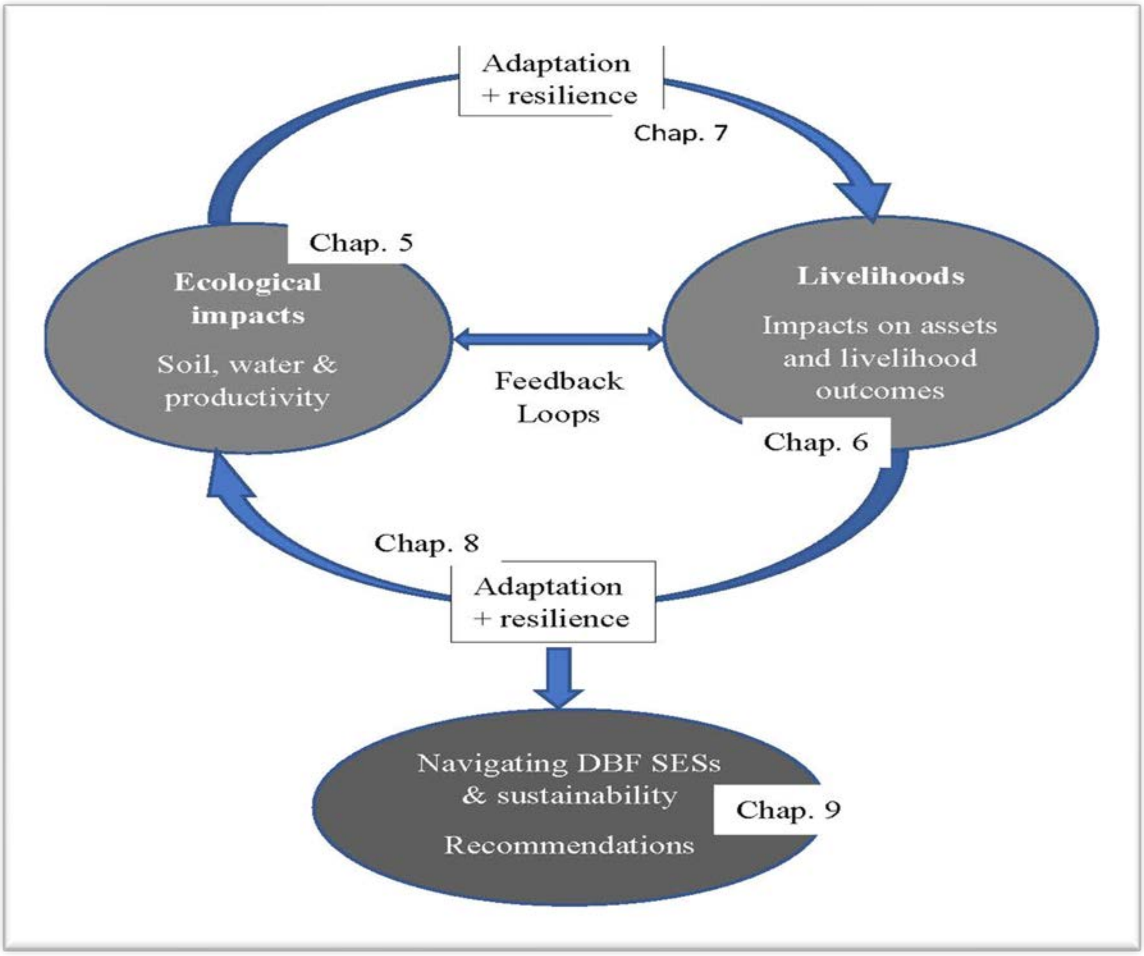


Figure 9.1 SESs model for investigating the DBF (from Chapter 3)

To better understand how the various aspects of the DBF's social-ecological systems interact and influence outcomes as presented in the four preceding chapters (Figure 9.1), this section presents key aspects of the DBF SESs model that helps visualise and explain interactions among various components of the system, outcomes and feedback loops

(Figure 9.2). Of paramount importance are the site-specific social-ecological factors that determine and influence what part of the DBF system is relevant for a particular area (Chapter 5) and for which livelihood categories of farmers (Chapter 6) represented by the green box in Figure 9.2. For instance, deep tillage and contour ridges may not be needed in undulating areas with sandy soils unlike places with clayey soils and steep slopes. Correspondingly, labour challenges among some farmers may complicate crop residue retention exercises relative to those who can hire additional labour while the prospects of saving on inorganic fertilizer purchases may result in some farmers willing to make time and labour trade-offs in making them (manure).

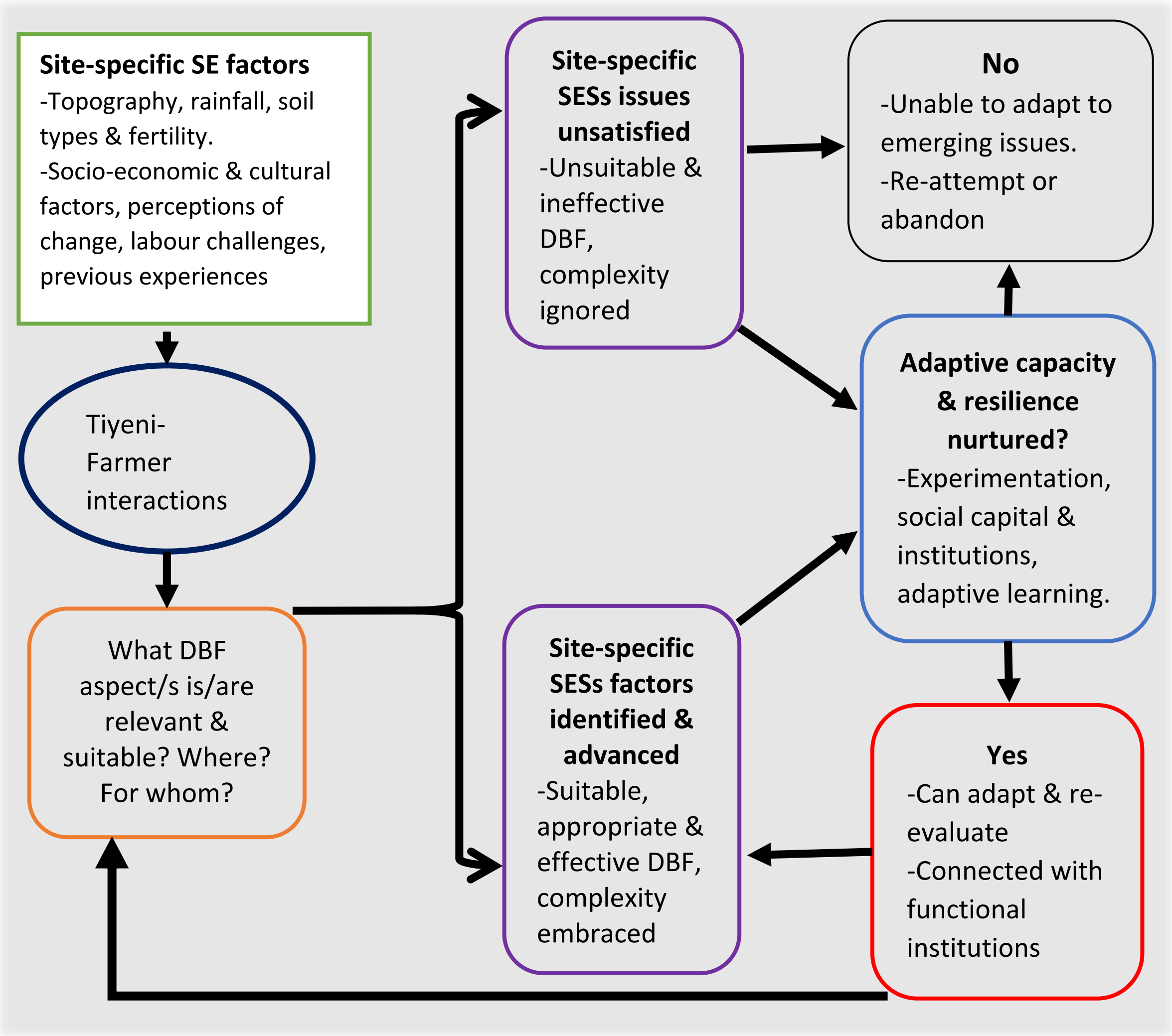


Figure 9.2 Aspects of the DBF SESs model, their interactions, outcomes, and feedback loops

Ultimately, what aspect/s of, and how farmers practise the DBF is also influenced by the types of Tiyeni-Farmer interactions that may enable or hinder appropriate selection of DBF aspects to be practised (dark circle below site-specific SE factors). Obvious issues pertaining to this include provision of handouts that contributes to farmers' failure to distinguish the DBF as a farming technology from Tiyeni as an organisation championing it (Chapters 5, 6 and 8). Moreover, extension approach and message delivery may worsen the situation among others because of failure to recognise and embrace possible DBF implementation challenges that potentially determine DBF system effectiveness. Chapter 8 also established that the type of Tiyeni-Farmer relationships have a profound effect on enabling or disabling farmers' local experiments that translate to DBF adaptation and modification, an important element of the adaptive capacity, resilience and sustainability of the DBF.

Outcomes from the above complex interactions fall into two; (i) site-specific social-ecological issues are satisfied and complexities that emerge through DBF practice are embraced or (ii) where these are not met as shown in Figure 9.2 (two middle boxes in purple). Where DBF is practised according to site-specific social-ecological issues, appropriate DBF aspects are identified and advanced, complexities anticipated and embraced, leading to effective system performance and positive outcomes (first outcome scenario). Within this space, adaptive learning and resilience are embedded along the DBF implementation cycle beginning with the first contact with a particular group of farmers. In the second scenario, complexities due to lack of site-specific social-ecological considerations and unhealthy Tiyeni-Farmer relationships make it impractical for smallholder farmers to effectively implement the DBF. Consequently, the system becomes ineffective, unattractive, and costly to sustain without the intervention of Tiyeni. Farmers in such situations have two options; re-attempt the technology to learn where things went wrong or to abandon it in search of suitable alternatives. Even in such cases, social networks and functional institutions can help struggling farmers cope with challenges they face and learn about possible solutions from colleagues within their local communities of practice where they exist or from their external connections with diverse DBF experiences (Chapter 8).

In both cases, farmers' adaptive capacity and resilience or lack of these determine the sustainability of the DBF system and practice (middle box in the far right). In the case of the latter, inability to adapt to emerging challenges in DBF practice leads to a less effective and unattractive DBF thus a farmer may decide to re-attempt the practice in the subsequent year or abandon it altogether (top right box in Figure 9.2). Conversely, farmers capable of adapting the DBF and making their practice more resilient are better positioned to cope with emerging challenges and sustain the novel farming system with or without the external intervention (bottom right box). The proceeding subsection expound these aspects as established Chapters 5 to 8 as basis for synthesising conditions that determine DBF sustainability or lack of it.

9.2 Navigating the sustainability of the DBF

Based on Section 9.1 above and the preceding four chapters, sustainability of the DBF as a package and its social-ecological impacts depend on three broad and interlinked elements which, according to the models presented above, help facilitate or hinder system effectiveness and sustainability. These include farmer-Tiyeni interactions and outcomes which influence crop residue retention and manure application (and associated issues), capacity for local adaptation and resilience, and farmer preferences and site-specific environmental factors. The discussion below considers how each of these determines sustainability outcomes across study sites and farmers of different livelihood assets.

9.2.1 Tiyeni-Farmer interactions and outcomes

The four preceding chapters have consistently demonstrated that interactions Tiyeni has with farmers partly determine the sustainability of the DBF among smallholder farmers across all study sites. Outcomes of these interactions positively or negatively affect what farmers practise, how they practise the DBF and whether farmers can effectively adapt the DBF according to their needs and emerging challenges. Under this theme, expectations and provision of handouts, blueprint approach to extension message delivery, and NGO political environment that create unnecessary competition for participants are the major interlinked issues.

(i) Handouts

Section 2.3 in Chapter 2 posits that promotion of CA practices in SSA was rooted in NGO relief work, combining provision of immediate material help with agricultural extension campaigns to contribute to farmers livelihoods resilience. After two decades of this practice, the start of a new CA promotion project is synonymous with handout provisions in the form of free start up seeds, fertilizers, implements and sometimes herbicides (Andersson & D'Souza, 2014; Giller et al., 2015; Mloza-Banda et al., 2016; Fisher et al., 2018). Correspondingly, farmers expect NGOs involved in this work to provide them with materials to use to implement the new technology (Chinseu et al., 2019). According to Chibwana et al. (2012), Holden & Lunduka (2012) and Ngongondo et al. (2012), government's subsidies are part of the problem. The provision and sustenance of handouts influence the type of relationships and information flow among NGOs and farmers, fuel competition among NGOs, affect farmers' capacity for local adaptation and resilience and the overall performance of the technology in question. Several examples suffice this argument.

Chapters 2, 5 and 6 make several references to how the provision or expectation of handouts interfere with the sustainability of the CA practices and the DBF and create need for compartmentalisation of agricultural practices according to those providing material support for their implementation. Involvement of material incentives, according to Chapters 5 and 6, lead to farmers' failure to practise the DBF in line with their site-specific social-ecological conditions, the principal concept of this thesis. Consequently, farmers' ability to adapt the DBF to their local needs is compromised in favour of one-size-fits-all (Giller et al., 2009; Andersson et al., 2014; Giller et al., 2015). Because handouts create unhealthy NGO-farmer relationships where the receiving end feels obliged to positively reciprocate the good gesture of the those giving them free materials (Chinseu et al., 2019), consideration of what is appropriate and suitable for an area and individual farmer is obscured and undervalued. Consequently, farmers conform with parts of the DBF that may not add value or solutions to their quest for resilient agricultural systems and sustainable livelihoods. In the process, avoidable complexities arise while farmers' adaptive capacity and resilience to such challenges remain limited. Issues around crop residue retention and manure application illustrate complex interactions and outcomes associated with handouts as NGOs interact with farmers.

Crop residue retention and manure application are two key components of the DBF that help sustain the short-term soil and water conservation and maize productivity benefits as well as the technology's contributions to livelihoods. These two practices also hold the keys to unlocking soil ecosystem sustainability under the loosened physical conditions of the soil under DBF by constantly making organic matter additions to the soil, reducing oxidation and improve overall soil fertility across all study sites (Kassam et al., 2009; Steward et al., 2018; Asfaw et al., 2018). As these two also help to permanently protect the deep bed surfaces from direct raindrop impacts and heat from the sun, their constant practice is the major missing component to resolving labour complexities that arise due to need for maintenance tillage after first year of DBF practice. While the lack of crop residue retention in CA has been attributed to shortages accruing from limited crop biomass, roaming livestock and wildfires and competing uses (Rufino et al., 2011; Erenstein et al., 2012; Ngwira et al., 2014; Thierfelder et al., 2016; Mloza-Banda et al., 2016; Steward et al., 2018), this study finds that place-specific social-ecological conditions, handouts, top-down technology transfer and extension play equally important roles.

Because of the adverse impacts of handouts, rigid blueprints of what and how DBF must be practised (Section 9.1.1), and the general lack of support for adaptation, these two critical parts of the DBF are widely ignored or discontinued in all study sites. Consequently, the DBF becomes less effective, labour demanding and unattractive, creating conducive atmosphere for dis-adoption (and unsustainability). Provision of handouts results in farmers' assigning NGO names as labels for the farming systems the organisation sponsors. Because of this, smallholder farmers find it difficult to separate the technology from the NGO. Absence of handouts for the NGOs farming technology results in farmers paying less attention to what works and what needs to be upscaled in DBF. Crop residue retention, because it is not a customary practice among traditional cropping systems, becomes easily neglected, compromising the DBF's capacity to deliver its most salient functions and resultant livelihoods contributions. In Section 9.1, poor smallholder farmers are more susceptible to this handout problem given their limited capacity to buy their own inputs and implements. Wealthier farmers, however, may find handouts insignificant given their ability to afford their own resources, making them less likely to fall prey to this problem. In conditions like this, handouts may create conditions where the DBF is unsustainable unlike those individuals who are detached from expectations of handouts.

Under the same conditions, Chapter 7 established that farmers' institutions formed as part of DBF promotion are less effective in dealing with emerging social issues among themselves. For example, club/group leaders still rely on external arbitration (Tiyeni) for issues that could be easily resolved among themselves, implying non-effective and dysfunctional local institutions (Pretty & Ward, 2001; Pelling & High, 2005; Ostrom, 2007; McGinnis & Ostrom, 2014). Similarly, new social connections to fellow farmers were found to be short-term, dying out as active interactions among club members decrease with declining frequency of Tiyeni field visits to a particular place. While Farmer-to-Farmer extension has become an important aspect of effective agricultural extension systems (Masangano & Mthinda, 2012; Kundhlande et al., 2014; Khaila et al., 2015; Davis et al., 2016), its long-term usefulness among smallholder farmers also anchors around the sustenance of handout provision. Indeed, evidence indicates that effectiveness of lead farmers in Farmer Field Schools (FFSs) declines as incentives cease (Ragasa, 2017; Ragasa & Niu, 2018).

Recent studies in CA continue to advocate for the provision of material incentives to lead farmers to encourage them to extensively share knowledge with other farmers, arguing that lack of such motivations stifles farmer-to-farmer information exchange (BenYishay & Mobarak, 2014; Ares et al., 2015; Davis et al., 2016; Fisher et al., 2018). As evidenced in this thesis, such forms of incentivised CA lead to complex challenges among smallholder farmers which combined make it unconducive to sustain such practices. While farmers will appreciate material incentives and start CA practices in return (Corbeels et al., 2014; Andersson & D'Souza, 2014), complexities surrounding crop residue retention such as poor seed germination, problems working the field, weed infestation and breeding of crop-eating insects, mice and toads are left unresolved

(Chinseu et al., 2019). As they realise complexities of such practices on their own and compare CA promotion campaign messages, dis-adoption follows.

Already, understanding CA adoption in SSA under current incentive-based promotion approach is a contentious issue (Giller et al., 2009; Andersson & D’Souza). It remains unclear whether reported CA adoption figures across the SS represent those who genuinely take up CA practices as problem-solving technologies for their agricultural challenges. What is well acknowledged, however, is the fact that dis-adoption of these handout-associated technologies after material support ceases is common in this region (Lalani et al., 2017; Fisher et al., 2018; Chinseu et al., 2019). On the other hand, dealing with this challenge may require concerted efforts from both the NGO and public sectors to realise that despite spending so much financing promotion of potentially beneficial farming technologies, their own approach defeats their purpose.

(ii) Blueprint issues

While its important that a farming technology is appropriately practised, having rigid blueprints of how every farmer needs to apply it negates the essential components of the novel farming system. in addition to obscuring the importance of site-specific considerations that determine what aspects of the technology is relevant for which farmers, such approaches lead to unhealthy relationships between the promoters of the technology and the farmers they work with. As established in Chapters 7 and 8, adaptive co-learning and management along the DBF implementation cycle is an essential element of a sustainable system (Gunderson & Holling, 2002; Folke et al., 2002; Hoffmann et al., 2007; Milestad et al., 2010) as it allows for improvements tailored to specific needs while generating solutions to DBF implementation challenges such as labour complexities and technology suitability. This is an iterative process between farmers and extensionists throughout the implementation of the DBF by embedding a horizontal exchange of information and enhancing feedback and co-learning between farmers and Tiyeni.

For instance, Tiyeni can observe and learn from farmers on how inherent environmental factors and farmers’ livelihood assets endowments influence which aspects of the DBF is/are relevant. Furthermore, specific adaptations to the DBF components can also provide Tiyeni with insights into how to streamline their extension messages according to site-specific social-ecological scenarios. Actively observing and supporting local adaptations to the DBF instead of aiming to correct these due to the perception that they are anomalies due to limited farmer's expertise in DBF (Gunderson & Holling, 2002; Walker et al., 2006; Darnhofer et al., 2010; Sinclair et al., 2014) can be a win-win situation for both farmers and Tiyeni.

Tiyeni can use this information to update and enrich their extension manuals that would be based on unique social-ecological conditions. This adaptive learning on the part of Tiyeni can facilitate relevance of their extension messages by designing trainings based on lessons learned from similar social-ecological conditions, thus avoiding promotion of DBF aspects that are not relevant for some communities and farmers. Eventually, farmers can focus more on what is likely to work under their conditions, avoid needless additional labour-demanding activities hence solving some of the critical issues in DBF. Similarly, adaptive co-learning can initiate active support for local DBF adaptation through experimentation which can help farmers generate DBF knowledge specific to their social-ecological situations. Furthermore, farmers in such conditions may become less reluctant to reveal and share their DBF experiences and experiments. Through local connections, smallholder farmers enhance independent learning, help others re-evaluate the effectiveness of various components of the DBF and help them make informed decisions on whether to sustain the DBF as a package, retain some of its key components or drop others, extend DBF plot sizes or abandon the technology entirely. The latter is less likely where extension systems create conducive environments for adaptive co-learning and facilitates local information exchanges.

Correspondingly, the lack of working relationships among NGOs like Tiyeni and grassroot leadership structures makes it difficult for farmers and Tiyeni club leadership to effectively resolve residue retention challenges that require the help of local authorities like village heads. For instance, roaming livestock and wildfires destroy maize stalks, creating serious crop residue shortages to sufficiently cover bed surfaces or as raw materials for manure making (Chapter 6). Because bylaws tackling these issues are non-existent, farmers who constantly lose their maize stalks to such causes may feel disenfranchised to continue crop residue retention or the protection of loosened soil structures from re-compaction by animal hooves or scorching by stray bush fires. NGOs such as Tiyeni can initiate partnerships with traditional leaders to raise awareness of the values of crop residues and to lobby or facilitate community bylaws based on specific situations. This co-management of the DBF extension process can enhance and embed local sustainability beyond sponsored practice. Eventually these conducive conditions for adaptive co-learning and management can also help devolve DBF technology ownership to farmers and conflict resolutions to grassroot leadership.

(iii) NGO politics

Whereas the unparalleled interest in the promotion of CA practices among NGOs across SSA has helped spread such technologies (Kassam et al., 2014; Mloza-Banda et al., 2016; Thierfelder et al., 2017), it has also led to unhealthy competition for participants among these key CA stakeholders. As an easy approach to boosting farmer participation in their agricultural projects and adoption thereof, NGOs have normalised the provision of handouts which creates complex power relations between farmers and NGOs (Aune et al., 2012; Andersson & D’Souza, 2014). Besides hindering farmers from separating the technologies being promoted from the NGOs promoting them, those found promoting the same or similar interventions in the same communities compete for the same participants.

Results of these grassroot level NGO rivalry further necessitates technology compartmentalisation according to who funds which farming systems. While marketing and branding of such technologies is important for NGOs, farmers’ failure to separate the DBF from Tiyeni creates dependence on external support such that lack of it makes the DBF, no matter how effective it may be, worthless and a burden. Key features like crop residue retention, manure making among others are adversely impacted, the technology’s effectiveness and its contributions to farmer livelihoods compromised. As NGOs aim to increase farmer participation in their projects, site-specific issues are superseded favour of imposing what worked elsewhere (Hay, 2010; Wood et al., Chinseu et al., 2019). Avoiding conditions like these can significantly lead to farmer adaptation, locally championed resilience and DBF sustainability.

As already argued, the promise of handouts in the early years of technology introduction does more harm than its intended goal. Local activities such as farmer-to-farmer extension become less prominent. As time passes without Tiyeni handouts, farmers' interest in continuing with any of the DBF interventions such as maintenance of the seed beds through retention of crop residues, making and applying organic manure, and maintaining box and marker ridges eventually declines. As these practices are left out, the effectiveness of the DBF is curtailed, except among innovative farmers for whom specific DBF aspects resolve some of their identified challenges or wealthier farmers who can independently afford high-priced inputs (Section 9.1). The culture of handouts is, at best, retrogressive in this construct than the complex nature surrounding crop residue retention and labour trade-offs in the practice of DBF and other CA interventions. On the other hand, those NGOs that fail to meet farmers' handout expectations stand to lose out to wealthier ones that have sufficient financial capacity to sponsor CA implementation among smallholder farmers.

9.2.2 Capacity for local adaptation and resilience

According to Section 9.1 above, local adaptation of the DBF parts according to an individual's social-ecological situations provide farmers with escape routes out of complexities around rigid DBF practice, and complexities around handouts. According to Chapters 7 and 8, farmers can build their adaptive capacity and enhance sustainability of their DBF social-ecological systems through their own on-farm experiments (Milestad et al., 2010; Hockett & Richardson, 2016) or by having connections to individuals and groups who do so or have different experiences of the DBF (Reij & Waters-Bayer, 2001; Folke et al., 2003; Crossley et al., 2015). As Figure 9.7 illustrates, enhanced adaptive capacity of smallholder farmers can help those lost in the confusion of power relations step back and re-evaluate relevance of DBF's parts according to their unique social-ecological conditions. Subsequently, it may also help smallholder farmers to move away from the DBF technology ownership dilemma (Section 9.2) to refocus their attention to what works on their farm. Indeed, some of the pressing issues in DBF like introduction of additional labour due to manure making and application processes can only be sorted out by experimenting with various components of the system to gain better understanding specific to the area in question as Chikwina farmers did (Section 8.2). Where these conditions are present, they may facilitate DBF's sustainability. Undoubtedly, absence of these conditions creates conditions that make the DBF unsustainable.

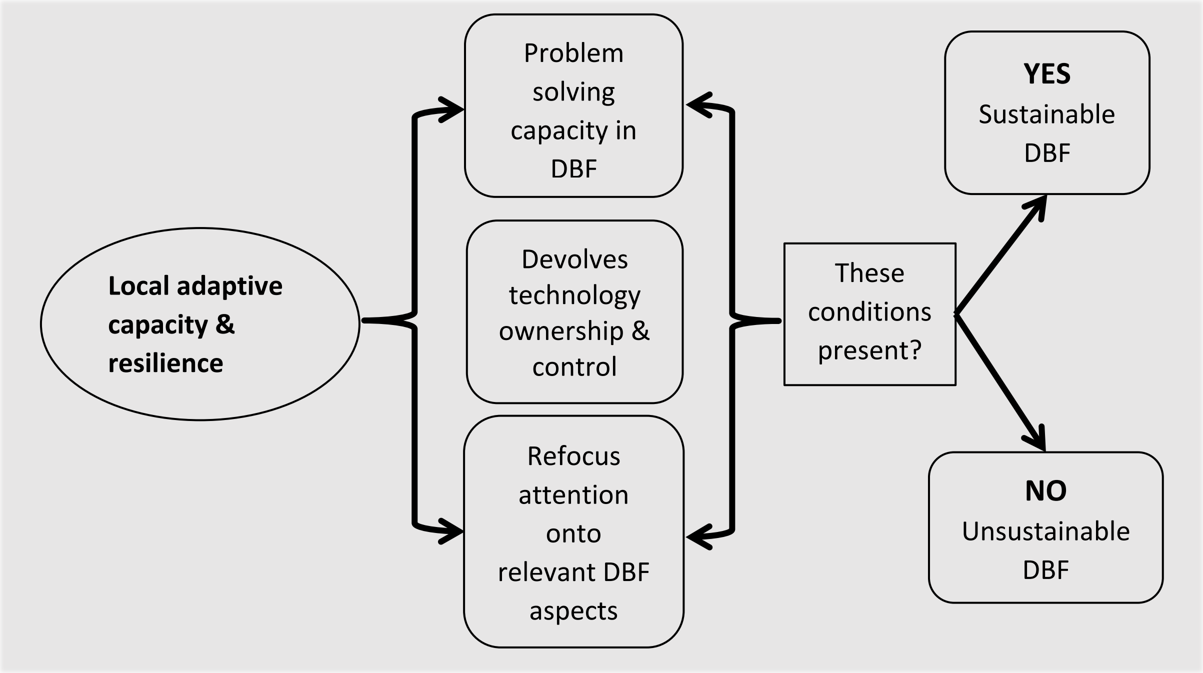


Figure 9.3 Farmers' adaptive capacity and sustainability of the DBF.

Section 2.4.5 showed that despite the importance of social capital and functional local institutions for enhancing smallholder farmers adaptive capacity (DFID, 2001; Spielman et al., 2011; Hermans et al., 2013; Scoones, 2015), these have either been poorly explored and utilised, or entirely ignored in CA research and practice (Ragasa, 2017; Khartaza et al., 2018). Findings in this study demonstrate the role of adaptive capacity through social capital and functional local institutions that could be the missing link in the sustainability of CA practices. As farmers are encouraged to interact and exchange information with those within and outside their social networks, they may learn new ways of dealing with specific CA challenges including those associated with poor crop productivity, labour challenges, crop residue retention etcetera. In the long-term, communities of practising farmers may develop place-specific CA knowledge to enable them cope with rising challenges without having to depend on external interventions, enhancing local sustainability in the process.

Streamlining DBF sustainability in the light of the DBF Model in Section 9.1 and outcomes in Section 9.2 requires that NGOs like Tiyeni make significant and flexible structural adjustments to their extension approaches that aim at eliminating institutional barriers at local and NGO level. Significant among these, as they apply to the two sections above, include adaptive co-management and learning, decentralisation of extension systems, recognition of site-specific social-ecological uniqueness, retrogressive NGO field rivalry, handouts, and diversification of their interventions.

In place of handouts, Tiyeni can focus on more impactful aspects in their extension structure such as enhancing local and external partnerships that can provide long-lasting value to these for the sustainability of the DBF (Section 2.4.6). The baseline participatory needs assessment activities suggested can be an important entry point in identifying site-specific DBF needs, foreseeable hurdles, possible solutions to crop residue challenges, needless labour complexities and who among the local authority ranks would be essential contributors to the sustainability of the DBF (Chambers, 1999; Cornwall, 2004). For example, Tiyeni can initiate working relationships with specific organisations or companies who can provide specific capacity needs trainings and services beyond Tiyeni's niche and how the DBF can be used as one of the key interventions among smallholder farmers pool of choices (Chapters 7 and 8). Some of these areas may be in the form of:

1. Dimba cultivation trainings
2. Crop and livestock marketing trainings
3. Farmer-to-farmer knowledge exchange visits
4. Organising inclusive farmer-centred field days
5. Leadership trainings for various clubs to strengthen their ability to organise themselves and resolve group conflicts
6. Engaging traditional leaders at different hierarchical levels such as the ADC, VDC, GVHs and VHs and how these can get involved in the establishment of suitable byelaws to effectively resolve local issues like crop residues and burning.

In the case where inherent environmental factors make most of the DBF components redundant, the above knowledge diversification strategies would help farmers develop other equally important skills and knowledge, providing them with extra benefits. Establishing farmer-centred partnerships are also important in that they also help farmers access other resources and information from stakeholders, widening farmers social connections and sources of information to inform DBF adaptation, resilience, and sustainability (Adger, 2003; Pelling & High, 2005; Crossley et al., 2015). These complementary activities and partnerships would help shift farmers expectations from handouts to focusing on solving their existing challenges and emerging issues raised in Chapters 5 and 6. Inadvertently, such value additions may also help Tiyeni to reduce their transaction costs in that farmers would stop depending on the limited number of Tiyeni staff. Trained partners with sufficient DBF knowledge can also help offer these services even when Tiyeni projects cease. Coupled with the improved engagement of the traditional leaders and local institutions like club leaderships, such value addition activities can help to build lasting knowledge base from which smallholder farmers can tap specific information for future DBF adaptation, resilience, and sustainability (Gunderson & Holling, 2002; Folke et al., 2002; Frenzel et al., 2019).

9.2.3 Farmer preferences and site-specific environmental factors

According to Section 9.1, topography, soil types and crop preferences among farmers determine which component of the DBF is suitable or relevant. Ability or failure to recognise these and streamline the DBF accordingly may become strong incentives or disincentives among smallholder farmers (Giller et al., 2009; Corbeels et al., 2014; Giller et al., 2015). In the first instance, recognising which parts of the DBF is relevant and why may help farmers focus on what is important according to their area and according to their individual social-ecological systems, which eventually helps them place value on such specific DBF components. Consequently, farmers can avoid unnecessary labour complexities and enhance their ability to sustain the technology without Tiyeni’s help. Furthermore, such incentives may boost effectiveness of the DBF in delivering social-ecological benefits for such farmers. Conversely, failure to recognise place-specific uniqueness leads to farmers getting lost in the struggle to practise the DBF as a whole, resulting in complex labour challenges as they waste time on irrelevant parts. Eventually, this group of farmers becomes indifferent and disenfranchised, leading to failure to engage in essential DBF activities. Outcomes from this include poor performance of the DBF which forms strong disincentives to abandon the technology altogether. Below are the specific examples of these interactions.

(a) Soil types and topography versus DBF relevance and suitability

Relevance and suitability of deep tillage, contour and box ridges as well as vetiver grass on a DBF plot are strongly determined by the type of soils and topography of an area (Section 9.1). For example, Malaya Nkhata with relatively flat terrain and highly sandy soils do not require deep tillage, contour and box ridges or growing of vetiver grass unlike Chikwina, an area with steep slopes and highly erodible soils. Training and encouraging Malaya Nkhata farmers to implement these unnecessary components means that farmers have to spend their limited time and labour implementing what they do not need to improve their farming systems. Consequently, these become labour burdens and compete with more important livelihood activities such as dimba cultivation and brick making (Chapter 6). Unquestionably, such situations create strong disincentives to abandon the technology or fail to pay more attention to relevant parts of the DBF. In conditions like these, the DBF becomes unsustainable because it fails to address the area’s inherent problems due to soil types and topography. According to Giller et al. (2015), learning from farmers’ long-term experiences and knowledge of their environment could be the difference between sustainable agricultural practices and the one-off experience of novel farming technologies which is the very foundation of agroecology (Weiner, 2003; Dalgaard et al., 2003; Gliessman, 2007; Wezel & Soldat, 2009; UNEP, 2012; Wibbelmann et al., 2013).

Conversely, recognising these unique social-ecological conditions may help farmers focus their DBF practice on more relevant parts like crop residue retention and manure application. Because these two DBF components may help such farmers significantly increase organic matter levels on their sandy soils (Erenstein, 2002; Kassam et al., 2009; Thierfelder et al., 2013a), they may value the DBF technology based on these two. High DBF effectiveness based on the performance of crop residue retention and manure application may become strong incentives for such farmers to internalise the practice as their own technology. In this situation, the DBF becomes sustainable by providing relevant solutions based on community needs and not a rigid blueprint of what the technology must be practised (Ojiem et al., 2006; Andersson & D'Souza, 2014; Giller et al., 2015).

Similarly, areas with undulating terrains, overused and degraded soils owing to limited land holding sizes and monocropping (Jalanthowa, Chipapa, and Mtavu) may find deep tillage and box ridges essential interventions in reclaiming and improving their soils. Enforcing planting of vetiver on contour ridges, however, may become disincentives to those farmers with least available land for growing their food. If this is not clearly recognised and taken into consideration in the early stages of DBF implementation, farmers who aim to fully maximise their limited land may see this as an opportunity cost and a burden, thus compromising even the other key components such as continued crop residue retention, manure application, box ridges, and the protection of deep beds from the destructive impacts of animal hooves and human trampling. As DBF effectiveness and contributions towards farmers' social-ecological systems decline, the DBF itself loses its value, making it unsustainable as time passes. Recognising site-specific issues like this one may facilitate the sustainability of the DBF (Ojiem et al., 2006; Knowler & Bradshaw, 2007).

(b) Crop type preferences and Tiyeni restrictions

While crop preferences according to place may appear insignificant a factor to influence overall DBF sustainability, Chapters 5 and 6 showed how the choice of which crops can and cannot be grown on DBF determines location of the technology, its effectiveness in delivering essential functions and the sustainability of the technology beyond Tiyeni's presence. While maintaining structural integrity is important for long-term use of these seed beds, crops involving digging during harvesting may be staple crops (cassava in Chikwina) or may provide essential additions to food availability to complement limited maize production where land is scarce (as in Mtavu, Chipapa and Jalanthowa). Not being able to grow these crops on DBF plots may mask the importance of the DBF as a system, reduce farmers interest in engaging in its associated activities and lose out on the technology's contributions to soil and water conservation and maize productivity improvements (Chapters 5 and 6). As farmers lose value of the DBF, its components become labour-demanding, thus providing rationale to abandon the technology when Tiyeni reduces its contact with such communities. Moreover, it creates situations where farmers compartmentalise farming technologies according to who sponsors and gives directions about how they must be used, inadvertently stifling local adaptation. All these represent situations that make the DBF unsustainable.

The freedom to grow crops of choice on a DBF plot can provide strong incentives to sustain the farming system and enhance system sustainability. It can also help enhance smallholder farmers' control of the technology to adapt and use it as relevant. For instance, farmers in Malaya Nkhata observed that cassava performed well on deep beds than their conventional ridges. While such farmers may not find value in deep tillage and other DBF parts, the ability to benefit from high cassava yields may become motivation for sustaining the technology past sponsored practice. Moreover, this enhances the DBF's contributions to a farmer's food security and income where sold. In such conditions, the DBF becomes sustainable.

9.3 Chapter summary

This chapter has synthesised key findings from Chapters 5 through 8, using them to model and understand complex interactions among key variables of the DBF social-ecological systems across six study sites and farmers of various livelihoods assets endowments. Section 9.1 have presented a model that represent most significant DBF SES components that draw upon various combinations of environmental factors, individual farmer's social-ecological situations, their social connections and their capacity for adaptation and resilience. These formed the basis for assessing the social-ecological sustainability of the Tiyeni DBF in northern Malawi in Section 9.2. More importantly, the Chapter has also provided examples of what entails a sustainable and unsustainable DBF besides the assessment of Tiyeni's extension system structural facilitators and barriers. Considering the overarching influence of handouts, NGO extension approaches, knowledge diversification and decentralisation of extension systems on the sustainability of the DBF, entry points have been suggested. More generally, this chapter and indeed the rest of the preceding ones, have demonstrated the importance of the Social-Ecological Systems approach in understanding complex issues surrounding the DBF and CA.

Chapter 10

Conclusion and recommendations

Chapter overview

This study has examined the social-ecological sustainability of the Tiyeni deep-bed farming system with an emphasis on how the social and ecological aspects of farmers' reality influence its place-specific effectiveness, adaptation, and long-term sustainability. Based on study objectives set out in Chapter 1 and reiterated in Chapter 2, Section 10.1 of this chapter summarises the main findings of this research in Chapters 5 to 8. The chapter also addresses the sustainability of the DBF, placing this discussion in the light of key facilitators and barriers in delivering resilience and sustainability among smallholder farmers while providing key implications, lessons learnt and recommendations in Section 10.3.

10.1 Key findings from each study aims and objectives.

This section summarises key findings and concludes each aims and objectives as evidence of the extent to which aims, and objectives of this research have been met.

10.1.1 DBF's impacts on soil and water conservation and maize yield response.

Despite questions surrounding the necessity and suitability of tillage elimination in CA (no-till) among smallholder farmers in SSA (Giller et al., 2009; Andersson & D'Souza, 2014; Giller et al., 2015) and the wide-spread evidence of problems arising from doing so (Govaerts et al., 2009; Mupangwa et al., 2012; Pittelkow et al., 2015a; Mazvimavi, 2016; Chinseu et al., 2019), tillage elimination remains a salient component of CA campaigns across the SSA. Despite crop residue retention being responsible for most of the CA benefits, proponents have made tillage elimination "*… a non-negotiable part of CA…*" (Fisher et al., 2018, p. 321). According to Giller et al. (2009), Andersson & D'Souza (2014) and Chinseu et al. (2019) the slow and poor adoption as well as dis-adoption of CA among these farmers arise from no-till's failure to provide immediate soil and water conservation benefits and improve or at least maintain crop productivity as in CR. Key findings in Chapter 5 of this thesis provide evidence that under compacted and degraded soil conditions among resource poor smallholder farmers, 'strategic tillage' and associated physical soil and water conservation features (Giller et al., 2009; Giller et al., 2015) remain key to sustainable farming in SSA.

The assessment of the DBF's impacts on soil physical parameters revealed that the technology results in immediate improvements of soil's rainwater infiltration, reduction in surface runoff volume, bulk density, and extent of soil erosion by half the quantities recorded in contiguous CR plots. Further analysis showed that these benefits are dependent on what aspect of the DBF farmers implement, the most important being the breaking of hardpans through 30cm deep tillage, water harvesting and preservation through contour and box ridges, manure application, crop residue retention and large surface size of the deep beds. According to DBF social-ecological models in Chapter 9, the choices to implement any of the DBF's key components like 30cm deep tillage, contour and box ridges, manure application, crop residue retention etcetera, is dependent on complex interactions and outcomes of a community's topography, soil types, amount and patterns of rainfall, crop preferences, individual farmer's social-ecological conditions and previous experiences with similar interventions.

Unlike other CA practices like no-till that are associated with maize productivity reduction (yield penalties) in the first few years with marginal improvements over a long time of consistent residue retention (Vanlauwe et al., 2014; Ngwira et al., 2014; Thierfelder et al., 2016; Kassam et al., 2017), this study revealed that the DBF increases maize productivity (high maize yields) in the short-term right from the first year of practice. Assessment of the response of maize productivity to dynamics in soil parameters due to DBF revealed strong correlations of maize yields to soil physical variables like soil erosion, water infiltration and bulk density. The implication being that as farmers engage in deep tillage to break down compacted soils, contour, and box ridges to contain and harvest rainwater and manure application as cheaper forms of inorganic fertilizers in the first year of DBF implementation, the soil improvements that take place right in that first year also results in improved maize productivity. In no-till systems, farmers are encouraged to grow crops on the same untilled yet compacted soil, leading to poor performance.

The study also reveals that there are marginal improvements in organic carbon, organic matter, and nitrogen levels in soils under the DBF: in both the short and long-term. Conversely, it was found that there exists a slight increase in soil electrical conductivity while pH remained constant. Similarly, phosphorus levels showed a declining trend which together with increases in electrical conductivity, suggest rapid oxidation of organic matter and leaching of ions under conditions where tilled soil is left prone to the adverse impacts of direct sunlight, raindrop impacts and extreme temperature fluctuations. Indeed, crop residue retention, manure application and cover crops, which form essential components of a sustainable agricultural soil ecosystems, were among the most neglected parts of the DBF.

The short-term soil and water conservation and maize productivity benefits in DBF showed declining trends when two- and five-year DBF plots were compared. Explaining such declining DBF effectiveness is the rapid soil re-compaction that takes place under conditions where beds are left exposed to the desiccating and crusting impacts of direct sunlight, erosive and surface-sealing impacts of direct raindrops. These challenges arise due to lack of crop residue retention and insufficient and inconsistent manure application that leave deep beds bare or insufficiently covered. Moreover, the pulverising effects of animal hooves and human feet exacerbate the problems, making the DBF increasingly ineffective. For instance, direct impact of raindrops causes the breakdown of soil colloids, splashing them off bed surfaces, causing rill erosion or bed surface sealing if not transported down the bed. While this sort of rill erosion may not account in the overall soil erosion data due to box ridges and closed plot edges in DBF, its adverse impacts on soil fertility and crop productivity cannot be discounted.

Since most farmers begin DBF practice without permanent organic soil cover, this rapid compaction begins right from the first year of implementation. Regardless of environmental characteristics, farmers who retained maize stalks on their DBF plots observed that such challenges were not prevalent, thus avoiding further tillage of the soil and saving on superfluous labour requirements that arise in attempts to loosen soils on DBF plots in the subsequent years. Such results concur with earlier findings that emphasise the importance of permanent soil organic cover in the form of crop residues (Powlson et al., 2014; Shaxson et al., 2014; Fisher et al., 2018). Continued and consistent practice of crop residue retention and manure application is mired in avoidable complex social-ecological interactions that either make them unattractive or unachievable, consequently limiting the effectiveness of the DBF and its impacts on the resilience and sustainability of smallholder farmers' soil ecosystems.

10.1.2 DBF's impacts on farmers' livelihoods

While per unit area analysis of maize yields showed high yields on DBF plots, several factors limit translation of such benefits into smallholder farmers' food security and income and consequently, livelihoods sustainability. Singularly, limited plot sizes under DBF means that the extent to which increased maize yields contribute to the overall household food security for any one of the farmers remains minimal. Likewise, income associated with sale of crop products from DBF plots is minimal granted the small quantities available for sale. Besides limited surplus crops for sale, inability to access better markets, underdeveloped local markets, and lack of smallholder farmers' cooperatives to take control of crop pricing further makes DBF impacts on household income minimal. Conversely, income savings for poorest farmers due to reduction in the need to purchase inorganic fertilizers and food has been widely acknowledged across all study sites. In CA, the need to purchase herbicides due to weed infestation (Ares et al., 2015; Vanlauwe et al., 2014) and maize yield reductions in the first years (Kirkegaard et al., 2014a; Pittelkow et al., 2015a; Chinseu et al., 2019) among resource poor farmers make practices like no-till have little impacts on livelihoods.

While labour complexities in no-till arise from weed infestation due to tillage elimination and problems surrounding crop residue retention (Kassam et al., 2014; Andersson & D'Souza, 2014; Chinseu et al., 2019), farmers practising the DBF face different challenges. Assessment of labour dynamics revealed that the DBF is more labour-demanding than CR owing to various factors. Firstly, deep tillage by hand requires considerable levels of strength and time to accomplish a small piece of land, making it difficult to increase land under DBF, limiting farmers' ability to fully maximise DBF's potential highlighted under Section 10.1.1. Similarly, manure making, and crop residue retention all introduce additional labour-demanding activities not normally practised under CR. Moreover, family labour is often unavailable owing to compartmentalisation of farming technologies associated with NGOs. Eventually, labour challenges may worsen due to power relations and lack of technology ownership among farmers due to handouts and top-down extension messages.

In terms of what variables account for the extent of DBF's contributions to household food security and income, it has been revealed that farmers' socio-economic characteristics had more influence than environmental uniqueness of the study sites (Chapters 6 and 9). To this end, four categories of farmers emerged. Among them, farmers with the least livelihood assets and limited strategies to escape their poverty significantly benefited from DBF' high yields that does not require them to purchase pricey inorganic fertilizers or herbicides. However, extending DBF plot sizes to maximise its benefits remains a significant challenge owing to limited resources to invest in upscaling activities besides being held up in power relations due to handouts. On the other hand, cash-oriented and wealthier farmers saw minimal DBF contributions to their food security and income given that they have some resources to produce enough food without engaging in labour-demanding DBF activities. Alternatively, these farmers stand to benefit the most should they commit to invest their own resources in DBF which could further help them accumulate more assets.

10.1.3 Tiyeni's impacts on farmers' social capital and institutional sustainability.

An examination of Tiyeni extension system' impacts on farmers social capital revealed that, incidental to formation of farmer clubs, farmer connections and interactions significantly increases among farmers of the same clubs and communities. Consequently, sharing of agricultural information increases, affording marginalised farmers opportunities to associate with influential farmers who bridge them with sources of information and resources beyond their reach. Labour sharing is a crucial resource for the elderly, those with health problems and widows who cannot afford to hire labourers. inexplicably, the extent to which any one farmer benefits from these new connections depend on how well they interact with others and suitability of the new knowledge gained.

On the other hand, it was also revealed farmers' connections to external networks remained negligible. Consequently, farmers fail to access unique DBF experiences from farmers external to their own communities. As a result, what farmers share in each group remains undiversified. Access to diverse DBF experiences from external networks of farmers can be an important contribution to farmers' adaptive capacity in the process of building locally suitable resilience and sustainability. Similarly, results showed that there exists a general lack of focus on enhancing farmers' local institutions, both through Tiyeni farmer clubs and working relationships with local authorities. Under this situation, farmer clubs tend to disintegrate, and farmer-to-farmer interactions cease over time. Consequently, sharing of DBF experiences and solutions to arising challenges gets compromised, limiting local adaptation, resilience, and sustainability of the farming system. This reduces local capacity for enhancing DBF institutional memory from which farmers can turn to should they face challenges such as roaming livestock and bush fires that destroy crop residues.

10.1.4 On-farm DBF adaptation and support for towards farmer experimentation

Concurring with DFID (2001), Scoones (2015) and Hockett & Richardson (2016) in Section 2.4.6, Chapter 8 revealed that DBF adaptation through on-farm farmer experimentation takes two major forms: the DBF package as one large experiment compared to CR and no-till and modifying and applying DBF's parts in various combinations. Farmers practise the DBF as part of their constant search for new and superior cropping systems that would resolve specific problems such as soil erosion, soil fertility degradation, increasing occurrence of droughts, dry spells, and heavy rainstorms as well as maximising production on limited and dwindling land sizes due land disintegration because of rapid population growth. Furthermore, this research found that, depending on an area's environmental characteristics, farmers adapted depth of deep tillage, evaluated the relevance of this and contour and box ridges, vetiver grass on contour ridges and introduced new types of crops and intercropping combinations outside the Tiyeni recommended ones. Owing to the additional labour demands in making manure, new formulae on how to make more effective manure types without increasing labour needs was also noted.

Decisions to sustain DBF (as a package), its components or to abandon the technology completely depends on outcomes of their DBF experimentation coupled with influence of handouts. Mismatches between farmers' experiences of the DBF with first year Tiyeni extension messages about the superiority of the technology may be used as basis for dis-adoption of the technology. While it remains unlikely that farmers would adopt the DBF as one complete package (as advocated for by Tiyeni), findings revealed that smallholder farmers retain some of the most important lessons learnt from such experiments and apply them on non-DBF plots. Consequently, farmers enhance their adaptive capacity to social-ecological challenges to build more resilient and sustainable farming systems.

While power relations due to handouts cloud the importance of specific DBF components for different farmers under unique social-ecological conditions, on-farm experimentation with individual parts of the DBF system appears to help farmers separate Tiyeni from DBF. For instance, farmers who applied deep tillage, mulching (crop residue retention) on plots other than DBF widely cited the importance these DBF parts. For farmers who observed no significant changes in soil and maize yields on their DBF plots, their new experiments helped them understand why the farming system was ineffective on their farm. Undoubtedly, these enhance farmers' ability to adapt to challenges such as unaffordable hybrid seeds and help them take ownership of their DBF plots.

10.2 The sustainability of the DBF system.

The DBF as a farming technology is both sustainable and unsustainable, depending on social-ecological conditions discussed throughout the preceding chapters and reiterated under this section. Except where labour is extremely scarce that a farmer cannot make deep beds, the DBF is both a sustainable and appropriate technology that can significantly contribute to the amelioration of food insecurity and acute poverty among resource poor smallholder farmers in Malawi and across SSA. Evidence in this research has shown that the technology:

- ✓ Does not require financial investments to effectively improve soil quality and increase maize yields. Due to deep tillage, contour and box ridges and manure application, smallholder farmers can halt soil erosion, prevent soil degradation, cope with dry spells and droughts and reduce risks of crop failure due to insufficient moisture or soil compaction. These are especially essential under smallholder farming in SSA because of prevalent poverty levels, increasing climate change impacts and economic turmoil.

- ✓ Both soil and water conservation benefits and maize productivity improvements take place from the first year of DBF implementation without having to rely on long-term crop residue retention as is the case in mainstream CA practices.

- ✓ Locally made manure saves poor farmers money they would have to spend on inorganic fertilizers and buying of supplementally food during lean periods. This is an essential coping mechanism. Moreover, manure is a vital component of a resilient and sustainable soil ecosystem that supports food production.

The technology becomes unsustainable under conditions created by complex interactions among failure in recognising site-specific uniqueness, NGO field rivalry, handouts, weak local institutions, and lack of Tiyeni support for farmer experimentation. Firstly, one-size-fits-all top-down approach to DBF extension results in Tiyeni encouraging farmers to implement unsuitable and needless DBF components, consequently creating discontent among farmers, loss of focus on what can work based on their (farmers') unique social-ecological situations. For instance, advocating for the implementation of deep tillage, contour and box ridges and planting of vetiver in locations with flat terrain and highly sandy soils only burdens farmers with unnecessary labour. If farmers' needs are to be matched, farmers in a place like this could be encouraged to implement crop residue retention and manure application. Similarly, making every farmer implement everything under DBF create situations where farmers no longer feel in charge of what they do on their DBF plots. Eventually, farmers lose interest to sustain even the important components of the DBF, making the farming system unsustainable. Restricting what types of crops can be grown on DBF has similar adverse impacts on sustainability.

It has also been revealed that there exists unnecessary competition for participants among NGOs promoting the same or similar CA-related practices in the same areas. To stand out of the competition, handouts are used. Eventually, farmers fail to separate the farming technologies and their effectiveness in contributing to social-ecological sustainability from those promoting them. The result has been the compartmentalisation of various plots belong to the same farmers, branding according to which NGO provides implementation support. While NGOs report high numbers of participants in their agricultural projects, farmers are left blinded in the mist of handouts or expectations thereof. As NGOs phase their projects out, technologies they promoted cease irrespective of whether the technology is effective and suitable or not. Moreover, handouts lead to several other complexities such as:

1. Undermines technology ownership on the part of the receiving smallholder farmers, making it difficult to sustain the DBF when Tiyeni stops its support.

2. Leads to a growing farmer dependence on Tiyeni, making it difficult for farmers to sustain even DBF components that do not require Tiyeni training like crop residue retention.

3. Weakening the effectiveness of local institutions that includes farmer club leadership and its capacity to provide localised leadership for Farmer-to-Farmer Extension (F2FE), conflict resolution among members and ability to effectively organise club members for collective work.

4. Undermines the role of the traditional leaders to engage themselves in the establishment of relevant byelaws that would help put a value on crop residues, facilitate disputes resolution and sustain and improve local institutional memory

to adapt to new social-ecological challenges without the intervention of external bodies.

5. Distracts smallholder farmers from understanding and harnessing the inherent potential of the DBF to improve their agricultural productivity. Consequently, smallholder farmers forego the opportunity to build resilient and sustainable cropping systems that could withstand shocks and pressures for temporary and insufficient material benefits.

6. Creates toxic power relationships between Tiyeni and farmers such that farmers' implementation of DBF becomes a token of appreciation for being given handouts (seeds, fertilizers, etc.) instead of an approach to help them build more resilient and sustainable farming systems.

7. The kind of participation and relationships above leads to and encourages a top-down information flow that is also associated with prescriptive forms of DBF and other CA practices and fails to meet farmers' site-specific needs.

8. Hinders local innovations and adaptation capacity since practising of what Tiyeni wants is thought to be directly reciprocal to the continued provision of the handouts and that variations from the same are viewed as (by Tiyeni) the result of insufficient knowledge among farmers.

The lack of functional local institutions also contributes to conditions that make the DBF unsustainable. For example, Tiyeni clubs are only functional if Tiyeni remains in contact. Similarly, farmer-to-farmer knowledge exchange independent of Tiyeni is generally lacking as is the involvement of local authorities who can help in conflict resolution and build DBF institutional memory for adaptation and resilience.

10.3 Lessons and implications for CA practice.

With reference to Section 9.2, this section discusses the implications of the key findings this research has presented to inform existing debates and contribute to refinement of future practice and policy. These border around the three key themes identified in Section 9.2 namely NGO-Farmer interactions, capacity for adaptation and resilience, and farmer preferences and site-specific considerations. Considering the key findings as discussed in this research, several recommendations can help facilitate the sustainability of CA.

10.3.1 Incentivised CA uptake

This thesis has established that incentivised DBF promotion does more harm than good. While recent CA literature continue to advocate for material incentives to enhance the adoption of CA practices and farmer-to-farmer extension, this thesis has discussed the adverse effects of handouts at length (Sections 9.2 and 10.2). Without needing much emphasis, handouts may have significantly contributed to CA's poor and slow adoption among resource-poor smallholder farmers across SSA. As already explained in Chapter, material incentives create toxic power relations, takes away technology ownership among farmers, hinders CA adaptation and re-innovation, creates unnecessary farmer conflicts, and nurtures farmers' dependence on external help. Combined, farmers are left in the mist of handout confusion, diverting their attention from how they can utilise CA practices to enhance their farming systems to how much fertilizers they would receive, who received more than the other among others. This compromises farmers adaptive capacity and the sustainability of CA among these farmers. More importantly, CA practices are no longer functional on their own.

It is also recommended that NGOs and research institutions interacting with farmers consider the gravity of relationships inclusion of handouts creates. Two options arise from this; either stopping the provision of equipment, seed and fertiliser handouts or at least separate it from the promotion of CA. The justification for this has been emphasised throughout this thesis. While it may be increasingly difficult for smaller institutions like Tiyeni to compete with wealthier NGOs who can still induce farmers using free inputs and tools, prioritising diversification of knowledge and experiences through enhancing farmer-to-farmer knowledge exchange initiatives, strengthening farmers' social capital and local institutions may enhance CA's adaptability and sustainability. While handouts can make many farmers join and try out a new farming system, evidence suggests that it is functional institutions that can sustainably support and enhance their long-term relevance.

Equally important are the ways in which extension messages are framed. Like Tiyeni's promotion of the DBF, CA extension messages are characterised by unrealistic promises of high maize yields, reduction in labour requirements and elimination of hunger and poverty (Giller et al., 2009; Andersson & Giller, 2014; Andersson & D'Souza, 2014; Ragasa & Niu, 2018). Practising these technologies to achieve such advertised CA benefits is more complex and challenging than extensionists make it to look like. Because extension systems in both DBF and CA fail to embrace expected implementation complexities, farmers finding them out on their own are easily disenfranchised, making it difficult for them to continue with the technologies. It is therefore important to reconsider how DBF and CA projects are framed, making sure that those in contact with farmers understanding the influence their use of terminology and interpersonal skills have on how farmers conceptualise and name the products they promote. How extension messages are delivered fundamentally influence farmers' evaluation of the effectiveness of CA. Unnecessary CA marketing and branding cliche′s are less likely to enhance sustainability beyond sponsored practice, but they definitely can influence farmers' dis-adoption.

10.3.2 Strategic tillage in smallholder farming in SSA

The lack of short-term benefits in many no-till based farming systems among resource poor farmers remains one of the challenges to the uptake of CA practices across the SSA. Indeed, growing evidence of CA dis-adoption in SSA indicates that lack of crop productivity increases, and yield reductions is the main cause of poor CA adoption across the region (Baudron et al., 2011; Pittelkow et al., 2015a; Arslan et al., 2014). As presented in Chapters 5 and 9, wide-spread soil compaction on farmers' plots, complexities associated with consistent and sustained crop residue retention, weed infestations due to lack of tillage and the resultant poor maize yields require that CA be flexible by abandoning the one-size-fits-all approach to its promotion. Regardless, no-till proponents continue to advocate for the elimination of all forms of tillage in the hope that long-term crop residue retention (which is largely neglected or complex to implement) would help reduce the compaction and contribute to stable crop productivity. This thesis establishes that tillage elimination without regard for site-specific soil condition checks exacerbates the mismatches observed throughout the past two decades of CA studies. Chapter 9 demonstrated that tillage elimination my cause more problems for smallholder farmers in specific social-ecological conditions.

Findings in Chapter 5 showed that the major problem to declining maize productivity under smallholder farmers is the physical degradation of soil parameters that develop due to compaction, poor rainwater infiltration, high soil erosion rates and the continuous loss of fertile topsoil. This research has shown that the DBF lead to immediate soil and water conservation improvements through deep tillage, contour and box ridges, manure application and the large surface area of the beds. These improve rainwater infiltration, reduce soil erosion, conserve moisture and results in improved maize yields that smallholder farmers are constantly searching for. It may be important, therefore, to understand that some locations still require some strategic tillage, others need the combination of this with physical soil erosion barriers such as contour ridges, yet others do not need all these. All they require may be crop residue retention and use of manure to help them achieve improvements of their inherently infertile soils on flat terrains.

Rightly so, the site-specific considerations remain relevant in deciding whether farmers in certain areas require tillage elimination, some type of tillage or just stand-alone permanent organic soil cover and organic fertilizers. Chapter 9 provides key considerations that represent many existing scenarios under Malawian smallholder agriculture. These could be important tools in deciding how to approach communities with new farming systems besides the DBF.

10.3.3 Adaptive co-learning and knowledge diversification

Besides recognising that everywhere is different and therefore CA practices must become adaptive, recognising the role of farmers in CA adaption is paramount in delivering sustainability. There is need for CA to recognise farmers as co-innovators. Given that local experimentations are specific to certain social-ecological conditions, CA can engage experimenting farmers to diversify CA practices and information portfolios. Eventually, locally suitable CA practices can enhance farming systems ability to cope with rising challenges associated with CA independent of its sponsors. Moreover, this thesis has argued that adaptive co-learning through farmer experimentation provides important escape pathways out of complex confusions created by handouts and top-down extension systems.

Correspondingly, adaptive co-learning among CA players and farmers is of paramount importance in that it helps create conducive environment for CA re-innovation for both farmers and external institutions promoting such practices. While farmers require guidance for novel farming systems that contain several parts, it is retrogressive to assume that every diversion from CA's blueprint is because of lack of understanding on the part of farmers. Rather, strive to understand why farmers omit one aspect of CA, modify another or stop practising the technology entirely. This can help build a diversified CA adaptation knowledge pool (or grassroots community of practice) that could be essential in streamlining future efforts elsewhere. As discussed already, local adaptations to CA through farmer experiments provides key pathways for farmers to step back from CA's dogma and power relations to re-focus their practice considering their specific social-ecological conditions. While this may appear disobedient or disrespectful to the outsider because farmers do not practise what they are trained to do, such adaptations are vital for farmers looking to enhance the resilience and sustainability of their farming systems.

10.3.4 Enhancing local institutions

The importance of functional local institutions cannot be over emphasised in delivering sustainability in CA (DFID, 2001; Scoones, 2015; Rendon et al., 2015). Among others, facilitating knowledge sharing among smallholder farmers requires the existence of strong institutions that can initiate knowledge sharing activities to improve farmers' social capital and diversify CA knowledge. Similarly, enhancing conflict resolution capacity of local leaders can make significant contributions to resolving challenges associated with crop residues (roaming livestock for instance). In both cases, farmers with access to current information about CA from external networks of farmers stand a better chance of coping with new challenges in their CA implementation. Collectively, social capital and local institutions may help build CA institutional memory that can be recalled as farmers face new challenges in the future, the very concept that defines adaptation and resilience.

10.3.5 Site-specific social-ecological systems considerations

Already emphasised, it is imperative that CA stakeholders and proponents consider site-specific social-ecological uniqueness before delivering CA trainings as they look to upscale their promotion efforts to millions of smallholder farmers across the SSA. This could be in the form of participatory baseline studies if no similar data exists to ensure that what is advanced among specific groups of farmers matches specific needs with specific CA components, thus preventing avoidable mismatches and needless additional labour demands. Also, this can contribute to adaptive learning in CA. This could be in the form of building diverse CA knowledge bases from various social-ecological settings by updating training materials with rich knowledge of how CA performs under different social-ecological scenarios. Such changes can significantly enhance CA effectiveness and contributions to farmers' social-ecological resilience and sustainability. Essentially, doing this would align CA promotion approaches to agroecological principles of blending long-term local social-ecological knowledge, farmer independence, and diversification (Dalgaard et al., 2003; Wibbelmann et al., 2013) which formed the basis for its development in response to effects of the Green Revolution.

Using the Social-ecological Systems approach in studying the DBF, this research has demonstrated the importance of taking on a more holistic approach to under suitability of and sustainability of CA. Through SESs (Ostrom, 2009; McGinnis & Ostrom, 2014), this research reveals the complex interactions among environmental and socio-economic uniqueness and how these interact and influence each other to determine what aspects of CA are relevant, where, and for which groups of farmers. Because most CA studies have largely failed to account for these interactions and outcomes and how they determine sustainability, unsuitable practices have been introduced to farmers who do not need them, creating needless complexities such as weed infestation, need for investing in herbicides, yield penalties among others. Taking on interdisciplinary and holistic approaches like SESs can significantly change CA practices and inform better policy directions.

10.3.6 Embracing complexity

Throughout this thesis, emphasis has been placed on embracing complexities that arise from site-specific social-ecological interactions where DBF is introduced. Similarly, CA stakeholders can work towards recognising that due to the complex nature of social-ecological systems farmers find themselves in, various outcomes are possible from their practice of CA. ensuring that farmers understand some of the complexities due to such factors can prepare farmers to face emerging challenges such as those associated with crop residue retention, reduced tillage and crop rotation and diversification. Negative experiences of CA that arise without farmers having thought of are potentially disincentives that may crowd out all the positive aspects of CA practices. To this end, It is vital that CA players recognise the importance of embracing the complexity of their work, realising that the seemingly beneficial technologies do not work for every farmer and that some of these may further complicate existing problems. Accordingly, extension messages meant to encourage farmers to adopt the technology must always make sure that they are framed with the understanding that certain farmers in certain communities will always face challenges that may make CA ineffective. Including such reality checks within CA trainings and extension messages can help lessen farmers disappointments when their experiences do match those advertised. Moreover, farmers have rich and diverse environmental knowledge about their areas. Making sure that expected hiccups are brought to farmers' attention early in the CA implementation cycle may help both sponsors and farmers to devise practical solutions.

When all is said and done, it is important to remember that smallholder farmers' needs are remarkably simple: sufficient food all year round while accumulating livelihoods assets to be better than they were yesterday. All farmers require is land and a hand hoe, or animal-drawn implements that can lessen the labour burden of digging the ground and make it possible to till a larger plot size. The DBF and other CA technologies are not the only vehicles to achieving these goals. Rather, they form part of many pathways to achieving these livelihoods aspirations. Independent of external interference and complexities that come along them, the DBF can be one vital method that can help millions of farmers struggling with chronic food shortages and acute poverty to fight their way out of such vicious circles of impoverishments and destitution. As they say in Tumbuka:

'*Njala na ukavu ni uzga ukulu'* (hunger and poverty are the greatest forms of slavery).

Note on previously published work: Mvula & Dixon (2020).

The paper titled “*Farmer experiences of Tiyeni’s dee-bed farming conservation agriculture system in Malawi*” published in 2020 is not in any way related to this PhD work. The research work conducted prior to its publication relate to a short-term survey done in May 2017 by Albert Mvula as well as field notes by Dr. Alan Dixon. Its citation in this thesis is like any other sources of information that have been appropriately acknowledged in-text and listed in the references section.

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Appendices

Appendix 1 Participant consent form

The Social-Ecological Sustainability of Tiyeni Conservation Agriculture method in Malawi

Consent form

Research purpose and procedures

The Social-ecological Sustainability of Tiyeni Conservation Agriculture in Malawi is a three-year research project that seeks to analyse the impacts of the deep-bed farming system promoted by Tiyeni Malawi in the 45 km radius of Mzuzu City. Albert Mvula, a student at the University of Worcester, is carrying out this work under the supervision of Dr Alan Dixon, principal lecturer in geography. The aim of this research is to identify the extent to which the deep-bed system contributes to win-win situations between deep-bed farmers' livelihoods and their environment in the areas where it is practised. This work involves a combination of methodologies, both quantitative and qualitative. Ecological aspects such as soil quality parameters, hydrological monitoring, and erosion monitoring and hydraulic conductivity will involve on-farm experimentation, sampling, yield measurements and laboratory work of soil and water samples. Objectives 2 to 4 of this work requires the use of Participatory methods where farmers will be involved in activities such as group discussions, individual interviews and field visits meant to answer specific questions. You may participate in this work through group discussions and participatory activities, and individual interviews to understand your livelihoods in connection with the new farming method.

Risks and discomforts of the research study

This research will not involve any risk and discomfort to participants. However, group work may take longer than the normal group meetings held on your set day and time. In that case, snacks and drinks will be provided where group meetings exceed the usual time for meetings.

Rationale for participation and Potential benefits

The study has many benefits to both farmers using deep-bed farming system and Tiyeni Malawi. This work will help Tiyeni to recognise both positive and negative impacts of the system and deal with the negatives and enhance the positive impacts for the benefit of the wider community of farmers. Tiyeni staff will also reflect on their extension approaches and make them work for farmers whom they serve. Further, this work will help Tiyeni be recognised for their work in Malawi and the international community which will help them expand their work to other areas where the method is also needed. In addition, the results and publications from this work will feed into the production of learning and teaching materials for primary, secondary and university students about the deep-bed farming system in the long-run. The results of this work will be explained to your group after finishing writing up of all chapters so you can see how your data has been used.

Alternative procedures

Confidentiality: All information about your participation will be anonymised unless you agree that your information be used without anonymization. The information you will provide will not be shared with anyone else in line with the Data Protection Act, 1988 and other legislations that protect your right in research.

Voluntariness and the right to withdraw your consent: Your participation in this research is voluntary. If you decide to sign this form and participate in this work, you do have rights to withdraw your consent and retract your information you already provided at any point in time. Withdrawal from the research does not carry any penalties and no one will ask questions as to why you decided to withdraw your consent. Contact details are provided below in case you want more clarification before or after signing the form or if you want to withdraw from the research study.

Contact details of the research

In case there is any need for more information, concerns or need to withdraw your consent after signing it, please contact Albert Mvula through the following contacts/addresses:

UK contacts
10 College Yard, WR1 2LA, Worcester, UK.
Mobile number: +447472913165.
Email: a.mvula@worc.ac.uk

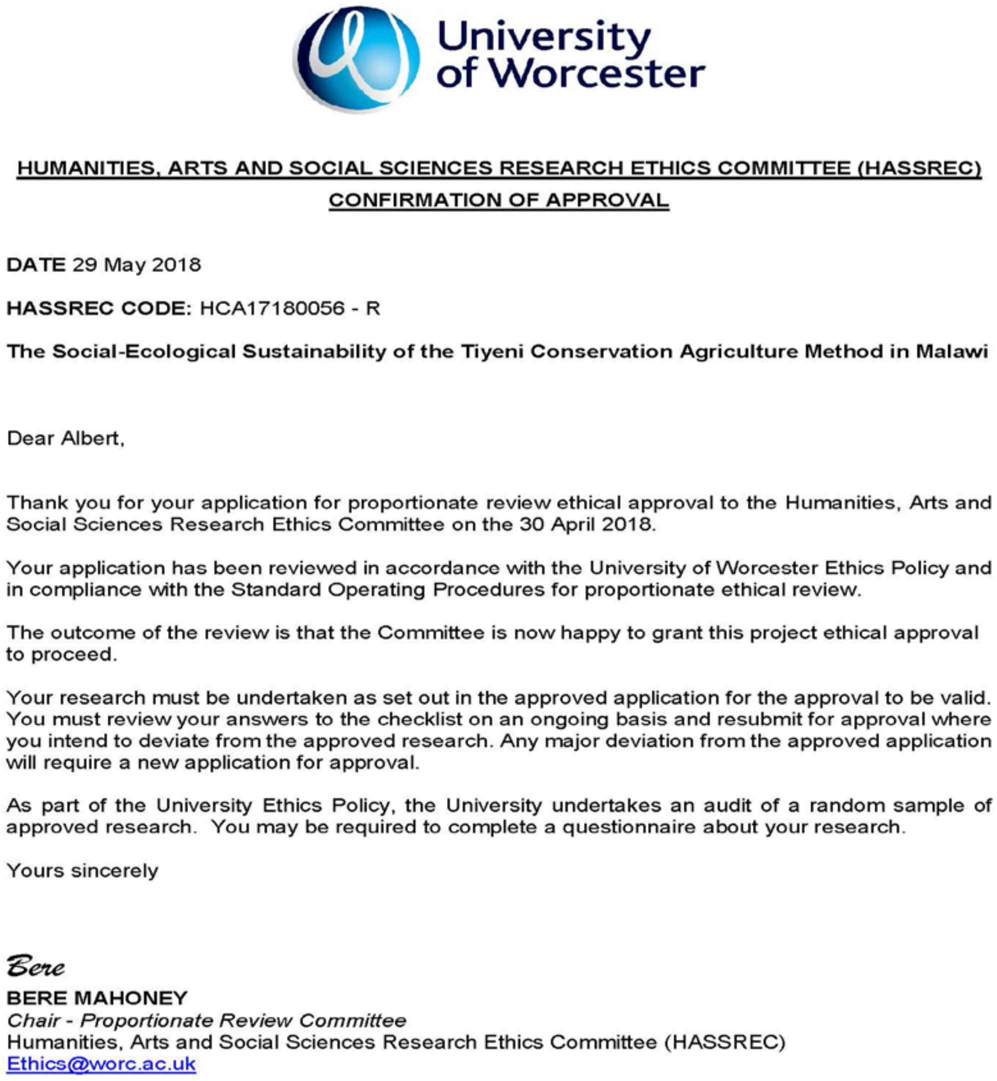
Malawi contacts
Tiyeni Malawi, P.O. Box 429, Mzuzu, Malawi.
Mobile number: +265881895949.

DECLARATION

(Participant)

I,……………………………..………..of……………………………………village/group hereby give my voluntary consent to take part in this research after being fully informed of the nature of the project and my participation on this day…………………………

Appendix 2 Research ethics approval



University of Worcester

HUMANITIES, ARTS AND SOCIAL SCIENCES RESEARCH ETHICS COMMITTEE (HASSREC)
CONFIRMATION OF APPROVAL

DATE 29 May 2018

HASSREC CODE: HCA17180056 - R

The Social-Ecological Sustainability of the Tiyeni Conservation Agriculture Method in Malawi

Dear Albert,

Thank you for your application for proportionate review ethical approval to the Humanities, Arts and Social Sciences Research Ethics Committee on the 30 April 2018.

Your application has been reviewed in accordance with the University of Worcester Ethics Policy and in compliance with the Standard Operating Procedures for proportionate ethical review.

The outcome of the review is that the Committee is now happy to grant this project ethical approval to proceed.

Your research must be undertaken as set out in the approved application for the approval to be valid. You must review your answers to the checklist on an ongoing basis and resubmit for approval where you intend to deviate from the approved research. Any major deviation from the approved application will require a new application for approval.

As part of the University Ethics Policy, the University undertakes an audit of a random sample of approved research. You may be required to complete a questionnaire about your research.

Yours sincerely

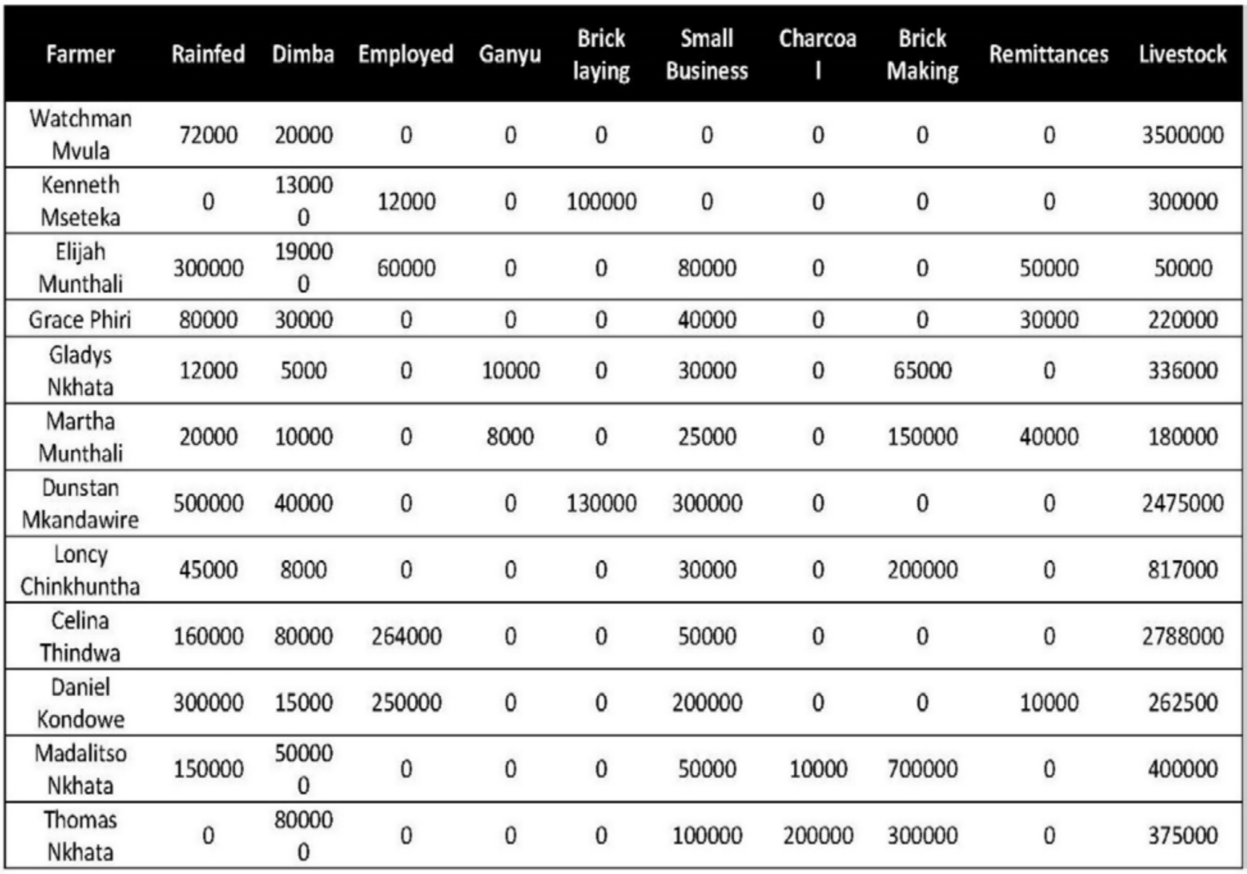
Bere

BERE MAHONEY
Chair - Proportionate Review Committee
Humanities, Arts and Social Sciences Research Ethics Committee (HASSREC)
Ethics@worc.ac.uk

Appendix 3 Correlation matrix for extracted principal components with significant values (p< .05) in bold.

		pH	**EC**	**P**	**OC**	**OM**	**N**	**BD**	**Erosion**	**Infil. rate**	**Maize yields**
Correlation	pH	1.000	.273	.280	.222	.239	.248	.209	.123	-.010	.192
	EC	.273	1.000	.130	.353	.336	.310	.265	-.065	.242	.386
	P	.280	.130	1.000	.083	.101	.126	.288	.303	.132	.231
	OC	.222	.353	.083	1.000	.984	.949	.236	.141	.201	.316
	OM	.239	.336	.101	.984	1.000	.989	.209	.131	.174	.294
	N	.248	.310	.126	.949	.989	1.000	.188	.130	.143	.275
	BD	.209	.265	.288	.236	.209	.188	1.000	.707	.689	.748
	Erosion	.123	-.065	.303	.141	.131	.130	.707	1.000	.459	.492
	Infil. rate	-.010	.242	.132	.201	.174	.143	.689	.459	1.000	.533
	Maize yields	.192	.386	.231	.316	.294	.275	.748	.492	.533	1.000
Sig. (1-tailed)	pH		**.030**	**.027**	.065	.051	**.045**	.077	.202	.474	.096
	EC	**.030**		.189	**.007**	**.010**	**.016**	**.035**	.331	**.049**	**.003**
	P	**.027**	.189		.288	.246	.197	**.024**	**.018**	.186	.057
	OC	.065	**.007**	.288		**.000**	**.000**	.053	.169	.086	**.014**
	OM	.051	**.010**	.246	**.000**		**.000**	.077	.188	.119	**.021**
	N	**.045**	**.016**	.197	**.000**	**.000**		.100	.189	.166	**.029**
	BD	.077	**.035**	**.024**	.053	.077	.100		**.000**	**.000**	**.000**
	Erosion	.202	.331	**.018**	.169	.188	.189	**.000**		**.001**	**.000**
	Infil. rate	.474	**.049**	.186	.086	.119	.166	**.000**	**.001**		**.000**
	Maize yields	.096	**.003**	.057	**.014**	**.021**	**.029**	**.000**	**.000**	**.000**	

Appendix 4 Income sources



Farmer	Rainfed	Dimba	Employed	Ganyu	Brick laying	Small Business	Charcoal	Brick Making	Remittances	Livestock
Watchman Mvula	72000	20000	0	0	0	0	0	0	0	3500000
Kenneth Mseteka	0	130000	12000	0	100000	0	0	0	0	300000
Elijah Munthali	300000	190000	60000	0	0	80000	0	0	50000	50000
Grace Phiri	80000	30000	0	0	0	40000	0	0	30000	220000
Gladys Nkhata	12000	5000	0	10000	0	30000	0	65000	0	336000
Martha Munthali	20000	10000	0	8000	0	25000	0	150000	40000	180000
Dunstan Mkandawire	500000	40000	0	0	130000	300000	0	0	0	2475000
Loncy Chinkhuntha	45000	8000	0	0	0	30000	0	200000	0	817000
Celina Thindwa	160000	80000	264000	0	0	50000	0	0	0	2788000
Daniel Kondowe	300000	15000	250000	0	0	200000	0	0	10000	262500
Madalitso Nkhata	150000	500000	0	0	0	50000	10000	700000	0	400000
Thomas Nkhata	0	800000	0	0	0	100000	200000	300000	0	375000

Appendix 5 Name and resource generator

Name of respondent: Celina Thindwa Age: ___________ Marital status: ______________

How many of these do you have; Chickens? ________ Goats? ________ Pigs? _________ Cattle? ____________

Name	Do you share any of the following information or knowledge with each of the following club members?					Is he/she still doing deep beds?	Did you connect by virtual of being in same Tiyeni club?
	Farming	**Markets**	**Loans**	**Share food**	**Labour**		

Of the people, organisations and groups you have mentioned above, do you know if they know, share or interact with one another?

Appendix 6 Livelihoods survey instrument

The social-ecological sustainability of the deep bed farming system in northern Malawi

A quantitative study of the impacts of the deep bed farming system on farmers' livelihoods in Mzimba and Nkhata-bay

Albert Mvula

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Cell: UK +447472913165; Malawi +265881356937

SECTION A. BACKGROUND INFORMATION

Name of interviewer ………………..……………………………..

Date of interview...……………………...

Group/community...…....………………………….........................

SECTION B. SOCIO-ECONOMIC CHARACTERISTICS

1. Name of respondent ………………………………………

2. Sex:

   1. Female
   2. Male

3. In which age group are you?

   1. 15-25 years
   2. 26-45 years
   3. 46-65 years
   4. 66-85 years

5. More than 85 years

4. Marital status:

1. Married,
2. Widowed
3. Divorced
4. Separated
5. Prefer not to say

5. Level of education.

1. Did not go to school
2. Lower primary (classes 1-4)
3. Upper primary (classes 5-8)
4. Secondary school
5. Tertiary

6. How many are you in your household? …………………………………………..

9 a. What type of land do you have access to/own? (Tick all that apply)

1. Forest land
2. Ordinary agricultural/farming land
3. Dambo land
4. All

9 b. How much agricultural land do you have access to?

1) Less than 1 acre
2) 1-2 acres
3) 2-3 acres
4) 3-4 acres
5) 4-5 acres
6) More than 5 acres

9 c. How much of dambo land do you have access to?

1) Less than 1 acre
2) 1-2 acres
3) 2-3 acres

4) 3-4 acres

5) 4-5 acres

6) More than 5 acres

10. How did you gain access to the agricultural land you cultivate now?

1) Passed on from parents

2) Given by a village chief after moving to this area

3) Rented land

4) Bought land

5) Borrowed land

6) Given by a friend

7) Other: Please specify

11. How large is your deep bed plot?

1. 0.25 acre

2. 0.5 acre

3. 0.75 acre

4. 1 acre

5. More than 1 acre

SECTION C. FOOD SECURITY

12. In the last 5 years, did you ever cut the size/number of meals because of food shortage?

1. Yes
2. No
3. I cannot remember.

13. If yes in 14, how often did this happen?

1. Almost every month
2. Some months but not every month,
3. In only 1 or 2 months
4. Don’t remember.

14. In the last 12 months, did you ever cut the size/number of meals because of food shortages?

1. Yes
2. No

3. Don’t remember.

15. If yes in Q14, how often did this happen?

1. Almost every month
2. Some months but not every month,
3. In only 1 or 2 months?
4. Don’t remember

16. If yes to Q14, how did you cope with the food shortage? Please tick all that applies.

1. Buying
2. Exchange for labour
3. Skip meals
4. Ate less desirable foods
5. Dimba cultivation
6. Relied on shared food from neighbours/relatives
7. Other: Please specify

17. The deep bed farming system has had no impacts on my household food security

1. Agree
2. Strongly agree.
3. There is no difference.
4. Disagree
5. Strongly disagree.
6. I don't know.

18. There are no differences in maize yields between the DBF and ridge-based system, only that DBF has more plant population than in ridges.

1. Agree

2. Strongly agree

3. Neutral

4. Disagree

5. Strongly disagree

6. Don’t know

19. Without fertilisers, the DBF does no better than conventional ridge-based system.

1. Agree

2. Strongly agree

3. Neutral

4. Disagree

5. Strongly disagree
6. Don’t know

20. The 30cm digging in DBF is not necessary because it does not improve crop rooting.

1. Agree
2. Strongly agree
3. Neutral
4. Disagree
5. Strongly disagree
6. Don’t know

21. Soil erosion in deep beds is the same as in the conventional ridge-based system.

1. Agree
2. Strongly agree
3. Neutral
4. Disagree
5. Strongly disagree
6. Don’t know

22. The yield differences between DBF and ridges is largely due to early planting.

1. Agree
2. Strongly agree
3. Neutral
4. Disagree
5. Strongly disagree
6. Don’t know

23. Ridges preserve more moisture than deep beds.

1. Agree
2. Strongly agree
3. Neutral
4. Disagree

5. Strongly disagree

6. Don’t know

24. There would be poor maize yields in deep beds without the application of fertiliser-manure mixture.

1. Agree

2. Strongly agree

3. Neutral

4. Disagree

5. Strongly disagree

6. Don’t know

25. Without crop residues, deep beds give very low maize yields.

1. Agree

2. Strongly agree

3. Neutral

4. Disagree

5. Strongly disagree

6. Don’t know

26. When are you more food secure comparing conventional ridges with deep beds?

1. There is no difference
2. On Conventional ridges
3. On DBF

27. On a scale of 0-10, how would you rate the contributions of the two farming systems to your household food requirements per year?

0 (no contribution at all)	**1** (negligible contribution)	**2 - 4** (slight to average contribution)	**5** (average contribution)	**6-8** (significant contributions)	**9-10** (ver significan contributi

27 a. Conventional ridges = _____________

27 b. Deep Beds Farming = _____________

SECTION D: INCOME CHANGES

28. Apart from rain-fed cultivation, which of the following do you do to earn money?
    1. Dimba cultivation
    2. Formal employment
    3. Piece works
    4. Remittances
    5. Sell of bricks
    6. Charcoal production
    7. Timber sowing
    8. Skilled labour (Tailoring, brick laying, house flooring etc.)
    9. Others: Please specify……………………………………….

29. Monthly household income

    1. 10 000 – 20 000
    2. 20 000 – 50 000
    3. 50 000- 100 000
    4. 100 000 above

30. Annual income from deep bed

    1. 10 000 – 20 000
    2. 20 000 – 50 000
    3. 50 000- 100 000
    4. 100 000 above

31. Annual income from conventional ridge

    1. 10 000 – 20 000
    2. 20 000 – 50 000
    3. 50 000- 100 000
    4. 100 000 above

32. Annual income from other sources

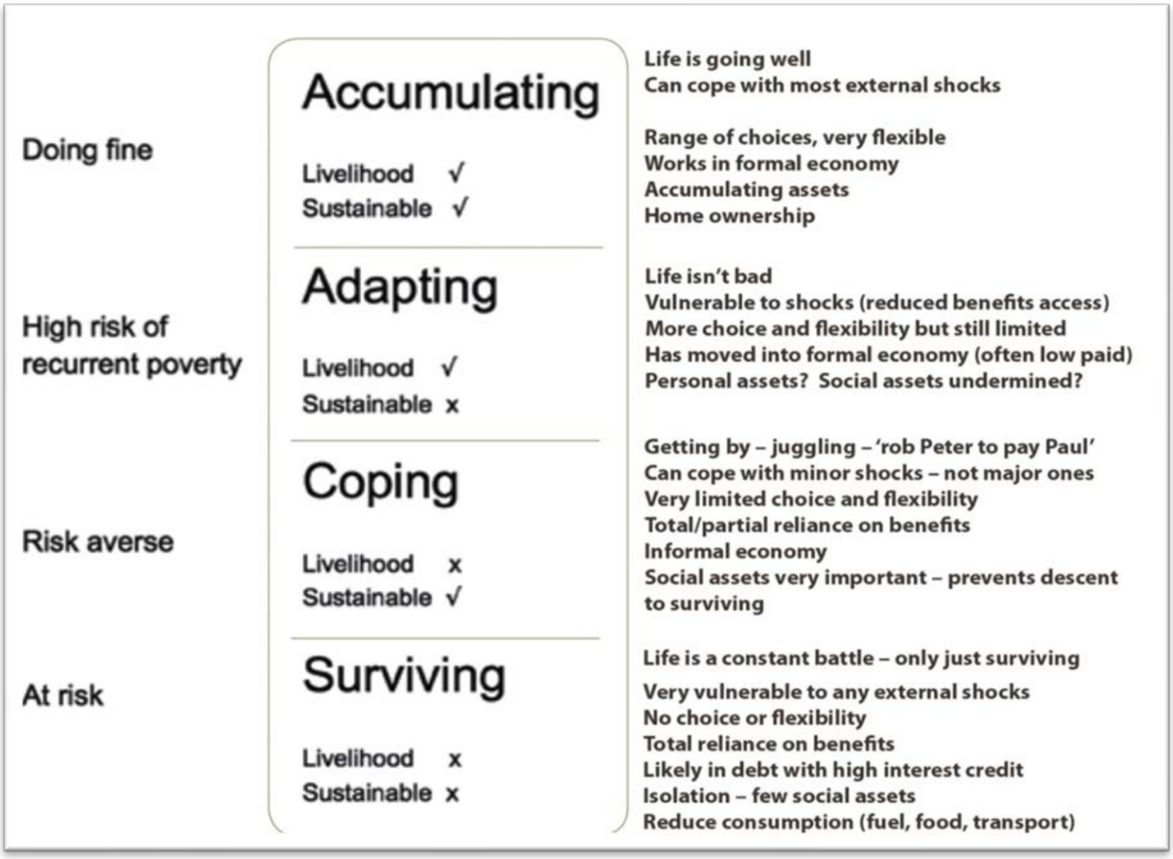
    1. 10 000 – 20 000
    2. 20 000 – 50 000
    3. 50 000- 100 000
    4. 100 000 above
33. When do you think you earn more money?
    1. No difference before deep beds and now due to poor markets/prices
    2. Before using deep beds
    3. After adopting deep beds due to surplus crop sales from deep beds
    4. Increased earnings after deep beds but not because of deep beds
34. What are your household priority expenditures? Tick all that apply.
    1. Prefer not to say
    2. Buying Food
    3. Clothes
    4. School fees

5. Renovating my house
6. Buying luxury items such as bicycle, radios and cell phones
7. Buy fertilisers and seeds on my own

THANK YOU VERY MUCH FOR YOUR TIME TODAY

Appendix 7 Livelihoods scoring index for Chapter 6, pages 154-161.

Analysis of DBF's contributions to farmers' livelihoods (Chapter 6, Section 6.4) showed that there are four farmer categories or groups with varying livelihoods assets and vulnerability levels, like Livelihoods Ladder (Index 1). To objectively decide who belongs to which group and therefore provide distributions and variations across the six study sites, a need for a suitable scoring system arose. Based on the Sustainable Livelihoods Framework (SLF), this scoring system was developed to help with this categorisation. It combines the five livelihood assets of the SLF namely Natural, Human, Financial, Social, and Physical assets with the vulnerability context, assigning numerical values to each of these assets to form a continuum divided into four categories. Each participant's livelihood assets and vulnerability were scored using this system to generate a numerical value used to place them into the four groups/categories of farmers in Section 6.4 and as it relates to the Livelihoods Ladder (May et al., 2009).



Doing fine	**Accumulating** Livelihood √ Sustainable √	Life is going well Can cope with most external shocks Range of choices, very flexible Works in formal economy Accumulating assets Home ownership
High risk of recurrent poverty	**Adapting** Livelihood √ Sustainable x	Life isn't bad Vulnerable to shocks (reduced benefits access) More choice and flexibility but still limited Has moved into formal economy (often low paid) Personal assets? Social assets undermined?
Risk averse	**Coping** Livelihood x Sustainable √	Getting by – juggling – 'rob Peter to pay Paul' Can cope with minor shocks – not major ones Very limited choice and flexibility Total/partial reliance on benefits Informal economy Social assets very important – prevents descent to surviving
At risk	**Surviving** Livelihood x Sustainable x	Life is a constant battle – only just surviving Very vulnerable to any external shocks No choice or flexibility Total reliance on benefits Likely in debt with high interest credit Isolation – few social assets Reduce consumption (fuel, food, transport)

Index 2 Livelihoods ladder adopted from May et al. (2009, p. 14)

Relevant variables under the five livelihood assets and vulnerability context were assigned with numerical values (Index Table 1). The sums of these variables are denoted as Highest and Lowest Aggregates (HA and LA). The sum of all highest aggregates for one farmer (HA_s) is calculated as the sum of the five asset and vulnerability scores (HAs). The same process was repeated to find the sum of the Lowest Aggregate (LA_s). Thus, the four groups of farmers fall between LA_s and HA_s. These values were used to calculate the range (R) of values within which the four categories are located and the interval (I) that separates them.

Index Table 1 Scoring system developed to categorise farmers according to Section 6.4.

Livelihood assets	**Variables considered**	**Highest score**	**Lowest score**	**HA**	**LA**
Natura assets	**Land ownership** (limited, adequate for now, more than enough)	3	1	9	3
	Soil fertility (Naturally poor, degraded, fertile but prone to degradation, fertile)	4	1		
	Crop diversity (undiversified, diversified)	2	1		
Human assets	**Education** (none; primary, secondary; college)	5	1	13	4
	Specialised trainings attended (none; few; many)	3	1		
	Labour availability (limited; enough; affords hired labourers)	3	1		
	Farmer health (Not good; healthy)	2	1		
Financial assets	**Stable income** (none; remittances; pension; formal employment)	4	0	12	3
	Business (sale of crops only; small-scale; taxi/maize mills)	3	1		
	Markets (Poor; good)	2	1		
	Savings & access to loans (Colleagues only; village banks; commercial banks)	3	1		
Social assets	**Societal influence** (holds no influential position; connected to NGOs; knows someone influential; influential person)	4	1	4	1
Physical assets	**Farming tools** (Struggles to replace worn-out tools; affords hand-held tools; owns animal-drawn tools)	3	1	7	3
	Storage facilities (Local storage only; affords storage pesticides)	2	1		
	Access to markets and services (bad roads; near good roads)	2	1		
Vulnerability	**Vulnerable to dry spells & unreliable rainfall?** (yes; can cope; not vulnerable)	3	1	8	3
	Financial emergency shocks (cannot cope; able to cope)	2	1		
	Susceptible to soil erosion & degradation? (Yes; Yes but can cope; No)	3	1		
	Total (HA_S and LA_S)			53	17

Range (R) = HA_S **-** LA_S = 53 – 17 = 36. **Interval (I)** = R/4 = 36/4 = 9

From the Scoring system above, the four livelihood categories fall between scores 17 and 53 spaced by an interval of 9 as follows:

Group 1 – The poorest of society, widows, & the elderly (surviving): 17 to 26

Group 2 – Cash-oriented farmers (coping): >26 to 35

Group 3 – Coping with moderate livelihoods (adapting): >35 to 44

Group 4 – Wealthy farmers (accumulating): >44 to 53