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Scaling up Conservation Agriculture in Malawi – an interdisciplinary analysis of agricultural innovation processes

by

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Declaration of Authorship

The candidate confirms that the work submitted is her own, except where work which has formed part of jointly-authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to work of others.

The publication Hermans TDG, Whitfield S, Dougill AJ, Thierfelder C. 2020. Bridging the disciplinary gap in conservation agriculture research, in Malawi. A review. *Agronomy for Sustainable Development* **40**: 3. DOI: 10.1007/s13593-020-0608-9, is included as Chapter 2 of this thesis.

The text was written by the candidate, with contribution from S. Whitfield, A. Dougill, C. Thierfelder. The candidate performed the screening and analysis of the data and created all figures and tables.

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Rationale for alternative format

The rationale for the alternative format thesis is that the variety in methods, theoretical background and integrated approaches used in this research, make it more appropriate to present each chapter as a separate paper.

All the work presented in Chapters 2, 3, and 4 is in the form of peer review published articles with the candidate as lead author. These chapters are the work of the candidate, with the exception of contributions of co-authors recognised in the preceding declaration of authorship. The use of three peer reviewed published articles as the three chapters meets the criteria for the alternative format thesis as laid out in the protocol for the submission of an alternative style of doctoral thesis by the Faculty of Environment at the University of Leeds.

The chapters are integrated into a cohesive discussion and conclusion on the overarching research objectives. The combination of chapters presented into one thesis provides evidence and discussion on the social, technical and political construction of knowledge in agricultural innovation, with Conservation Agriculture in Malawi as the case study.

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Abstract

Agricultural innovation is a high priority on the global sustainable development agenda to address land degradation, food insecurity and climate change challenges. As part of this agenda, Conservation Agriculture (CA) is promoted for enhancing agricultural resilience. Despite positive biophysical results, CA adoption in southern Africa has been relatively low. This has given rise to numerous CA studies on the agronomic performance and socio-economic constraints.

Departing from dominant literature, this research takes an interdisciplinary approach to evaluating innovation around CA, in which innovation is interpreted as a process of knowledge construction. I critically evaluate the role of knowledge and actors in agricultural innovation scaling across a multilevel innovation landscape. The empirical research is based on two Malawian sites, where CIMMYT promotes CA through on-farm demonstration trials, a knowledge interaction space. Secondly, I review the learnings of an interdisciplinary approach. Drawing on the technical, social and political knowledge construction, I make recommendations for effective innovation scaling.

Firstly, a mismatch is identified between innovation approaches in 'Research and Development context', which places emphasis on technical fixes and quantitative success metrics, and the dynamic multidimensional innovation processes in real world farm systems. Secondly, within farm systems, innovation processes are characterised by: (1) s*ocial dynamics & information transfer, (2) contextual cost & benefits*, *(3) experience & risk aversion,* and *(4) practice adaptation.* Thirdly, I develop and apply a novel approach integrating farmers' knowledges with technical soil measurements. This provides insights on the interactions between technical and social knowledge construction, and land management priorities. I situate these within the wider politics of knowledge around innovation scaling.

An interdisciplinary approach offers new insights, but comes with methodological trade-offs. Reflecting on these, I make recommendations, for organisations such as CIMMYT, focusing on: institutionalizing integrated learning, widening the interaction space, increasing feedback loops, and reflection and communication on assumptions about different knowledges.

The thesis abstract in Chichewa can be found in Appendix F.

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Abbreviations

ADD Agricultural Development District

ANOVA Analysis Of Variance

AIP Affordable Inputs Programme

C Carbon

CA Conservation Agriculture

CAM Conservation agriculture with sole maize

CAML Conservation agriculture with maize and legume intercrop

CI Confidence Interval

CP Conventional practice with ridge and furrow system

CIMMYT International Maize and Wheat Improvement Centre

CGIAR Consultative Group on International Agricultural Research

CSA Climate Smart Agriculture

FAO Food and Agricultural Organisation

FISP Farm Input Subsidy Programme

FSR Farming Systems Research

GDP Gross Domestic Product

GIZ Gesellschaft for Internationale Zusammenarbeit

GoM Government of Malawi

IPCC Intergovernmental Panel on Climate Change

MDS Minimum Dataset

N Nitrogen

NASFAM The National Smallholder Farmers' Association of Malawi

NCATF National Conservation Agriculture Task Force

NGO Non-Governmental Organisations

PAR Participatory Action Research

PIP Plan Intégré du Paysan

SDG Sustainable Development Goals

SRI Sustainable Rice Intensification

SSA Sub Saharan Africa

STS Science and Technology Studies

TLC Total LandCare

UN United Nations

VESS Visual Evaluation of Soil Structure

WoS Web of Science

Chapter 1

Understanding agricultural innovation scaling processes using an interdisciplinary approach

1.1 Research objectives

This thesis critically explores the role of institutions, actors and knowledges in the process of scaling agricultural innovation. Although literature distinguishes between the various ways in which scaling takes place (e.g., upscaling, outscaling, downscaling and deepscaling), here the overall term ‘scaling’ is used, to refer to “the adaptation, uptake and use of innovations such as practices, technologies, and market or policy arrangements across broader communities of actors and/or geographies” (Schut *et al.*, 2020: 1). The term ‘scaling’ is used critically throughout this thesis as it is closely related to the older terminology of diffusion of innovation (Rogers, 2003) and the scaling up agenda.

The thesis is based on empirical research at two sites in rural Malawi, where Conservation Agriculture (CA) is being promoted as a climate smart agricultural solution by the International Maize and Wheat Improvement Centre (CIMMYT) in collaboration with Government extension services and the environmental NGO Total LandCare (TLC). At these sites, CA is promoted through on-farm demonstration trials hosted by lead farmers. These trials represent spaces where knowledge sharing and interaction takes place between different agricultural stakeholder groups. Working within these ‘interaction spaces’ provides the opportunity to critically explore the constructed and political nature of agricultural innovation. The thesis brings together 3 inter-related studies that have been published in leading international journals, which represent integrated natural science and social science approaches, to collectively address the thesis’ first overarching objective:

Objective 1) To critically evaluate the role of knowledge and associated small holder farmer decision-making in the process of agricultural innovation for development in Malawi.

This is achieved by an analysis of the interaction between different knowledges, thereby gaining understanding of the processes through which agricultural innovation takes place. Knowledge connotes in this thesis the understanding of information combined with experience and analysis, enabling its use for a purpose or action in one’s specific context. The application of interdisciplinary research approaches offers insight into the complex nature of innovation, helps to expose the roles played by different knowledges and actors within them, and also offers an opportunity to reflect on the benefits and challenges of knowledge integration within the agricultural innovation 'interaction space'. I therefore also address a second overarching objective:

O**bjective 2)** To reflect on the learning opportunities, contributions and challenges of interdisciplinary research in the context of agricultural innovation and farmer decision-making.

This reflection in turn helps to shed a critical light on fundamental questions about what agricultural innovation is, and how it is conceived and measured (and therefore how it is scaled up), and by and for whom.

The academic and applied contributions of this thesis are threefold: 1) employing and evaluating an interdisciplinary approach to addressing knowledge gaps on CA innovation, which fall between disciplines, 2) providing in depth empirical insights on CA and on-farm demonstration trial dynamics within Malawi, and 3) evaluating the instrumental role of on-farm demonstration trials as spaces for the interaction and construction of knowledges. These contributions include the development and application of a novel approach to integrating farmers' knowledge, with technical soil measurements. This enables the critical analysis of the interactions between the technical and social construction of knowledge around CA, situated in a wider politics of knowledge around innovation scaling. Additionally, my reflections on the interdisciplinary approach provides learnings and recommendations for the wider agricultural development sector working across technical, social and political knowledges.

Box 1. Personal reflections on the PhD start, objectives and positionality.

My PhD started with an idea embedded in my educational background – learning across knowledges and disciplines to form a more holistic picture of agricultural innovation. During my first scoping trip to the CIMMYT trial with CIMMYT agronomists, self-doubt quickly hit me – as an interdisciplinarian you are never the specialist. I felt an outsider in many ways, from the farm systems and from agronomic scientists as the promoters of CA and the trials. As an outsider, I was, in the first instance, unclear about the trial agenda and design. However, looking back I realize this is where my questioning of linear technical diffusion and the larger landscape dynamics came in. During my PhD, my focus has moved into system thinking and constructivism, focusing increasingly on how the framing of knowledge influences the interaction and resulting innovation processes. Turning the position as outsider into a strength that could provide a new approach is eventually what guided me. I realized that writing about learning across knowledges and disciplines requires reflection on my own learning process and positionality. From the start, I needed to acknowledge the limits in my own knowledge background based on scientific and western education, and unlearn preconceptions in order to truly learn from stakeholders. I have reflected on many things; the interdisciplinary approach, my role of outsider and young female, what is participation, my connection to CIMMYT as international research institute, and my dual role of facilitator and observer of innovation processes. This reflection is implicit and constant throughout the chapters that follow, before being explicitly discussed in the final chapter.

1.2 Agricultural Innovation for Development: the case of Conservation Agriculture

Conservation Agriculture (CA) has long been promoted in Sub-Saharan Africa (SSA) as a sustainable form of agriculture, fitting to various agendas of the agriculture and development community. CA promotes the principles of 1) minimum soil disturbance; 2) soil surface cover with crop residues or cover crops; and 3) crop rotation or diversification with intercropping (FAO, 2017). These principles are, however, often promoted as specific practices with instructions to be implemented. These practices build on those traditionally used in African agricultural systems before colonial occupation, but more recently CA has been re-packaged and promoted in response to various sociological and ecological challenges. These challenges include soil erosion, agricultural resources costs, yield productivity of the land, food security, social equality, gender or climate change mitigation (Whitfield, 2015). Over time, different challenges and political agendas have arisen and the priorities of governments, international development donors and organisations have shifted accordingly. CA has consistently been proposed as an agricultural innovation that can address multiple challenges, although sometimes these claims have been underpinned by questionable or incomplete evidence bases (Whitfield, 2015).

Climate change is predicted to further increase the occurrence of extreme heat, extreme rainfall, higher average temperatures and drought events across SSA (Mbow *et al.*, 2019; Niang *et al.*, 2014). All of these climate changes will result in increased challenges for agricultural production and food security (Lobell *et al.*, 2011; Mbow *et al.*, 2019). To improve the resilience and adaptation of agriculture to climate change threats and soil degradation, the Food and Agriculture Organisation (FAO) proposed the climate smart agriculture (CSA) framework (Lipper *et al.*, 2014; Palombi & Sessa, 2013). CSA, as conceived by the FAO, has three characteristics: 1) it leads to a sustainable increase in agricultural productivity; 2) it improves climate change adaptation and resilience; and 3) it contributes to greenhouse gas emission reduction and carbon sequestration (Lipper *et al.*, 2014). Several agricultural practices have been proposed to be climate smart, including CA, agroforestry, alternate wet-drying in rice, improved rangeland management, and precision fertiliser application (Rosenstock *et al.*, 2016; Thierfelder *et al.*, 2017). CA is the most widely promoted CSA practice in SSA, particularly in southern Africa where it has a history of promotion under different banners (FAO, 2008; Richards *et al.*, 2014)

Studies from southern Africa on CA performance compared to conventional practices have reported improvements in soil water retention (Simwaka *et al.*, 2020; Thierfelder *et al.*, 2015c; Thierfelder & Wall, 2010), infiltration capacity (Ngwira *et al.*, 2012c; Thierfelder *et al.*, 2015c; Thierfelder & Wall, 2010), structure (Eze *et al.*, 2020; Simwaka *et al.*, 2020), biological activity (Ngwira *et al.*, 2012c; Thierfelder *et al.*, 2015c), crop yields (Ngwira *et al.*, 2012c) and heat stress resilience (Steward *et al.*, 2018). In this context, CA has been promoted as a sustainable land management approach that strengthens soil fertility, builds resilience to heat and dry spells, and stabilizes yields (Ngwira *et al.*, 2014a; Steward *et al.*, 2018; Thierfelder *et al.*, 2015c; Thierfelder & Wall, 2010). These yield and soil health outcomes represent a compelling evidence base that underpins claims about the potential for CA to improve farmers' livelihoods and strengthen the resilience of African food systems.

Despite the acclaimed benefits and international support for CA, these benefits have been shown to be context specific and dependent on soil, climate and socio-economic context (Steward *et al.*, 2018; Thierfelder *et al.*, 2015a). Nor are they proven to be universally economically beneficial for smallholder farmers in SSA (Corbeels *et al.*, 2020; Giller *et al.*, 2009). This may go some way to explaining the persistent low rates of CA adoption by small-scale farmers across SSA, for example in Malawi CA covers only 5.6% of the arable land (Kassam *et al.*, 2019). Various approaches have been used to understand and explain this perceived *paradox* of positive biophysical research results over a decade but low adoption rates.

From an agronomic perspective, evidence for CA benefits is often based on controlled research station studies and it has been recognised that the results from these controlled experiments can be different to those that are experienced in real life on-farm situations (Baudron *et al.*, 2011). For example, studies on research stations in Zimbabwe, Zambia and Malawi have recorded increased carbon stocks (quantity of C per unit area) under CA management compared to conventional management (Ligowe *et al.*, 2017; Thierfelder *et al.*, 2012) (0-10cm, 10-20cm, 0-30 cm depth). Conversely, studies at on-farm trials in Malawi reported both insignificant (Cheesman *et al.*, 2016) and significant differences in both C stock and concentrations (Mloza-Banda *et al.*, 2016, 2014; Ngwira *et al.*, 2012b; Simwaka *et al.*, 2020). These uncertainties have been recorded on a larger scale across southern Africa (Swanepoel *et al.*, 2018), and across SSA (Powlson *et al.*, 2016). Corbeels et al. (2020) conducted a meta-analysis covering 16 countries in SSA and reported that mean CA yields are only marginally higher compared to those of conventional systems. They conclude that CA provides soil health benefits but is not a short-term solution for low crop yields and food insecurity. They also suggest that higher maize yields under CA can be attributed to specifically mulching and crop diversification and that the largest improvements under CA are observed under low rainfall and with increased use of herbicides. This conditional success was also highlighted in a meta-regression by Steward *et al.* (2018), which showed CA outperforms conventional treatments when there is high heat stress, low N fertiliser application or sandy soils. Collectively, this evidence base points to the fact that the agronomic performance of CA is context dependent; and is a reason to question the external validity of this techno-scientific evidence base derived from controlled experiments.

In addition to studies of the agro-ecological benefits of CA, there have also been various studies reporting socio-economic constraints or adoption challenges for smallholder farmers. The main issues raised in these studies focus on the lack of sufficient residues or resources such as fertilizer and herbicides (Andersson & D'Souza, 2014; Brown *et al.*, 2018b; Giller *et al.*, 2009; Ngwira *et al.*, 2014b), information access and lack of knowledge (Brown *et al.*, 2018a; Chinseu *et al.*, 2019; Fisher *et al.*, 2018; Ngwira *et al.*, 2014b), the mindset of the plough (Andersson & D'Souza, 2014), challenges in the wider market, institutional and policy context (Andersson & D'Souza, 2014; Brown *et al.*, 2017; Chinseu *et al.*, 2019; Dougill *et al.*, 2017), the role of promotional input subsidies (Andersson & D'Souza, 2014; Brown *et al.*, 2018b), labour bottlenecks (Ngwira *et al.*, 2014b), community health systems (Jew *et al.,* 2020), or incompatible environmental conditions (Rodenburg *et al.*, 2020). Demographic models have also been used to understand what factors influence adoption, such as the availability of hired labour, and farming group membership

(Ngwira *et al.*, 2014b). Some authors also suggest different manners of assessing adoption numbers, through evaluating lead farmers' practice familiarity, recommendation and adopters (Holden *et al.*, 2018), or focusing on the adoption decision-making process as separate decisions on each of the CA practices (Ward *et al.*, 2018).

In this thesis, Chapter 2 will firstly critically analyse existing literature and dominant approaches to evaluating CA innovation. This analysis helps to highlight the need for an alternative interdisciplinary approach. By subsequently adopting an interdisciplinary approach, this thesis will scrutinize the concept of adoption and innovation processes by conceptualizing agricultural innovation as a multifaceted process of (social, political, technical) knowledge construction in Chapters 3 and 4.

The importance of context is apparent in the increasingly proven misconception that CA systems can be applied in the same way across diverse farm systems. Instead, CA may be more appropriately understood as a basic set of principles, as opposed to specific practices as instructions, that need regional and local adaptation (Thierfelder *et al.*, 2015c). The need to take into account context, scales and multi-dimensionality to understand the CA paradox is evident in studies that aim to evaluate and understand CA introduction, feasibility and adaptation (Corbeels *et al.*, 2014; Giller *et al.*, 2015). However, the question of how innovation actually happens in relation to CA has often not been considered (Ndah *et al.*, 2020). To understand this, this thesis approaches CA as a process of innovation which is formed and developed through interactions between institutions, actors and knowledges within specific contexts. This helps to shift focus away from the constraints on, and conditions for, CA adoption, towards a more nuanced understanding of what innovation looks like, and therefore what it means to scale up CSA (Glover *et al.*, 2016; Sumberg, 2005, 2017; Sumberg *et al.*, 2012b; Whitfield, 2015).

1.3 Conceptual Framework: Agricultural Innovation for Development and the Innovation Landscape

1.3.1 Agricultural Innovation for Development

Within agricultural development, innovation has been at the forefront of institutional agendas, including those of international donors, and agricultural research and development organisations. Agricultural innovation is often thought of as a new technology or practice (e.g. CA). These concepts in this thesis are used interchangeably as both refer to the application of knowledge for practical agricultural goals. Based on a technical concept of innovation, the linear model of diffusion and knowledge transfer, as extensively discussed in Rogers (2003), has been the dominant theory of change for understanding how technologies can translate into positive development outcomes. In this conventional model, innovation development takes place under controlled experiment conditions (Sumberg, 2017), and this provides the evidence base that underpins a top-down dissemination (i.e. ‘diffusion’) of technologies to farms, or transfer to other geographical regions. In this process, the tested agricultural innovation is removed from the research context and ‘packaged’ for dissemination (Glover *et al.*, 2017). This dissemination of technologies is typically coupled with introductory training and instructions via demonstrations, extension officers, or lead farmers.

At the core of this theory of change is the assumption that a positive demonstration of technological benefits by innovation leaders (e.g., extension officers and lead farmers), will result in linear diffusion to and uptake by users (e.g., the wider farming community). These users are rational decision makers, judging on the relative advantage of the new technology or practice over their current practice in their respective contexts (Rogers, 2003). This diffusion model has an underpinning assumption about the ability to group potential users based on geography or demographics; it assumes a level of homophily (i.e. similarity among users) (Rogers, 2003). Consideration of context within linear models of innovation diffusion has often been limited to technological or biophysical aspects, rather than engaging with the social contexts in which knowledge is shared and communicated.

The wider institutional context to this diffusion of innovation is that there is a competitive pressure on agricultural research and development actors to convince donors of their particular technological solution and secure financial support. Providing success stories about the uptake and impact of agricultural technologies is an important way in which these actors justify their work and secure funding (Sumberg *et al.*, 2012a). To provide these success stories, measurements are needed to show impact on the ground. This in turn creates the need for measurable indicators of success, and rates of technology adoption represent attractive metrics of impact-at-scale objectives. A top-down impact-at-scale technology transfer model has become the framework within which much research on innovation takes place. This has implications for what questions are asked, methods employed and data collected, when it comes to analysing innovation.

The main critiques on this linear diffusion of innovation model emphasize the lack of acknowledgement of multidimensional and diverse farm systems contexts and power dynamics (Andersson & D’Souza, 2014; Glover *et al.*, 2016; IAASTD., 2009; Sumberg, 2017) . Scholars from science and technology studies (STS) (e.g. Sumberg, 2017) and the literature on information landscapes and extension services (Leeuwis & Van den Ban, 2004), question simplistic narratives around the ‘rational’ adoption of innovations. They emphasize the socially constructed and contested nature of agronomic knowledge, seeing this instead as knowledge that is dynamically developed and negotiated through networks of various actors and institutions (Thompson & Scoones, 1994). It is formed through contesting and interacting beliefs, principles, ideas, and interests, and is embedded in a historical politics of development (Rogers, 1983; Thompson & Scoones, 1994).

From a more nuanced understanding of agricultural innovation as a process of knowledge construction, farming can be conceptualised as an ongoing form of innovation, embedded in socio-economic and agro-ecological contexts, in both time and space (Richards 1989, 1993). This concept of agriculture as a process of innovation has methodological implications for those seeking to evaluate it. Drawing on the case study of Sustainable Rice Intensification (SRI) Glover (2011) adopts a technographic methodological approach, which presupposes that technology consists of both technical and social parts which can change over time and space. A technographic approach focuses on farmers' behaviours, choices and interactions in context (i.e. ethnography of technology-in-use*)*, without dismissing the diversity and dynamics of real world farm systems. I conceive of agricultural innovation as a process of knowledge construction, involving exchange between actors and institutions (including between farmers and research organisations) embedded in historical politics of development. Knowledge is conceptualised as the ability to use information, combined with experience and analysis for a purpose or action, in one's specific context (based on Leeuwis & Van den Ban, 2004; Bates, 2005 and Savolainen, 2017). A technographic methodological approach is employed within the research presented in Chapters 3 and 4.

1.3.2 Innovation landscape

The construction of knowledge around CA involves institutions, actors and associated knowledge based in various social contexts. This thesis critically explores how agricultural innovation is formed within, and by, these social contexts. I have divided these into the Research and Development context, and farm systems context; together these context form what I have called 'the innovation landscape' (Figure 1.1), which is centred around the interaction space as the starting point.

Before discussing each social context and the interaction space, it needs to be acknowledged that actors and institutions are present in all these contexts. Whereas actors are the individuals and organisations making up the social contexts, 'institutions' are widely conceptualized as the rules, and social structures of interactions between actors (North, 1990; Ostrom, 2011; Kristianson et al. 2017). In particular the work on New Institutional Economics frames institutions as the "rules of the game", both formal rules (e.g. CIMMYT, farmer union) and informal rules (e.g. social and cultural norms in farm systems) that shape actors' behaviour and interactions (North, 1990;

Ostrom 2011). The Institutional Analysis and Development Framework by Ostrom (2011) emphasizes the role of ‘action situations’ as the social spaces of interaction, exchange, problem solving or disputes. This can be translated to the vision for the on-farm demonstration trials as interaction spaces. However, critical institutionalists stress that ‘institutions’ as processes of interaction and rules are ‘fuzzy’ and adaptive, based on human creativity, history and the encountering of traditional and modern, formal and informal settings, and scales (Cleaver & De Koning, 2015). This framework and argument on the coming together of different norms, perceptions, and values within the interaction space, underpins 1) the importance of approaching agricultural innovation as a process of knowledge construction, and 2) the important role of the interaction space in this process.

The outlined Agriculture Innovation for Development context (section 1.3.1) evidences that institutions are also an important part of agricultural innovation, since governments, private and public sectors influence innovation development (e.g. market policy, ‘impact-at-scale’ and technology focus). The role of these institutions has been emphasized in for example the Agricultural Innovation System framework (e.g. Spielman et al. 2009). Building on this work, the focus of this thesis is on the role of the interaction space in shaping innovation in farm systems. Here institutions are present in the form of social or cultural norms or as influence from the Research and Development context through the interaction space.

In my conceptualisation of the innovation landscape, the top part of Figure 1.1 is the Research and Development context, characterised by the passing down of knowledges, assumptions, innovations and imaginaries of development. This consists of donors (e.g., development agencies, government, NGOs) and the CGIAR Centres (e.g., CIMMYT) or other research and development organisations who, based on their agendas and goals, develop targeted programmes and projects. These are implemented using constructed settings and tools to interact with the target audience, namely farmers. The farmers form the target of the outward diffusion (and scaling up) of innovation, however, they are themselves simultaneously engaged in multidirectional knowledge exchanges and learning within and across their communities and farm systems. Interaction between Research and Development and farming systems contexts takes place largely through constructed settings, such as demonstration trials, farmer field schools or extension services. These settings make up the ‘interaction space’.

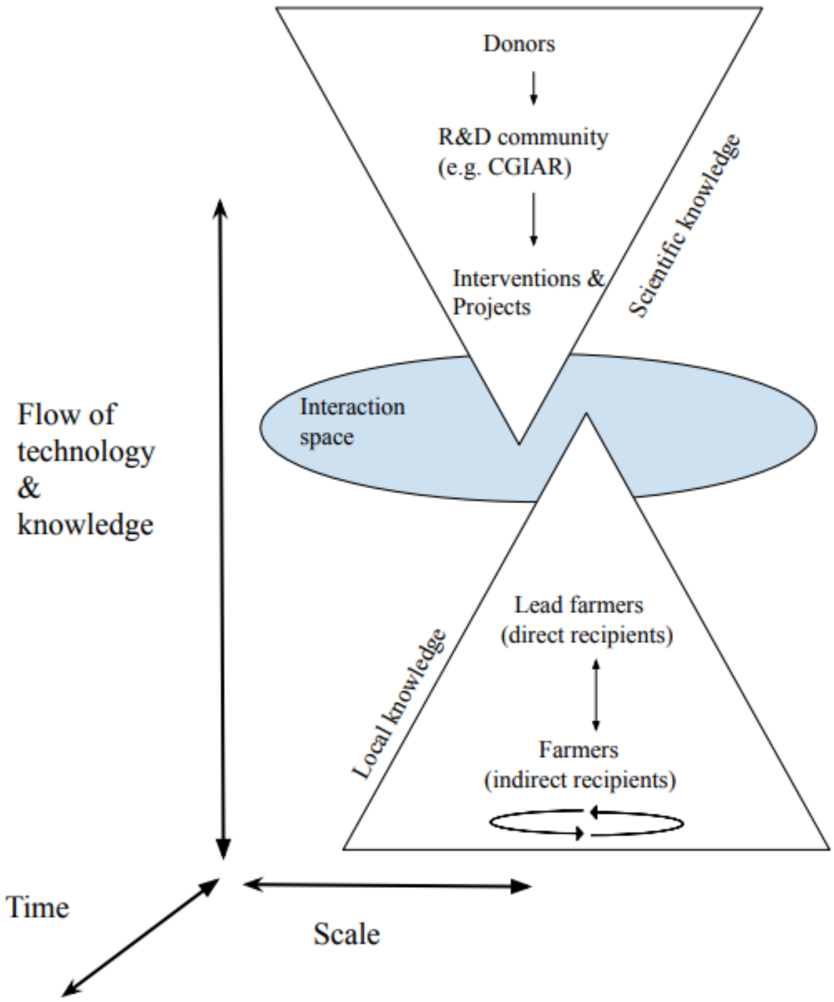

Figure 1.1 The innovation landscape social contexts: Research and Development context, associated with scientific knowledge, and farm systems, associated with local knowledge. Both knowledges and social contexts interact as indicated with the interaction space. Time indicates that these contexts and interactions are dynamic.

The components of the innovation landscape are often analysed critically, but separately and within different academic and disciplinary fields. This study comes from the premise that understanding CA innovation requires an understanding of the connection and interaction between different social contexts and therefore learning across disciplinary fields. This thesis applies an interdisciplinary approach to critically exploring agricultural innovation across these social contexts.

Chapter 2 considers the approach taken within current research to evaluate and 'measure' agricultural innovation. This highlights the dominance of techno-scientific studies, and critically evaluates the existing interdisciplinarity in agricultural innovation research. Following from this analysis, showing the need for interdisciplinary thinking and methodologies, Chapter 3 and Chapter 4 focus on objective 1 analysing how agricultural innovation takes place in the farm systems context. Chapter 3 focuses on the interaction space and farmer decision-making on CA's impact on soil health (as main promoted CA benefit) based on the interaction between scientific knowledge from the Research and Development context, and experiences within farm systems. Lastly, Chapter 4 focuses on the farm system experience, outlining the diversity and processes in agricultural innovation decision-making as influenced by the farm system wider context.

1.3.2.1 Research and Development context

International donors have played a significant role in the construction of the epistemic community around CA promotion (Andersson & Giller, 2012), through providing resources, and coupling CA promotion with humanitarian aid and development agendas. Furthermore, their involvement with international research organisations, most notably the Consultative Group on International Agricultural Research (CGIAR), supported the building of a CA evidence base, which added a form of knowledge legitimisation (Andersson & Giller, 2012). For the CGIAR, the CA package conforms with its history of focusing on technological dimensions of agricultural change (Leeuwis *et al.*, 2018) and its green revolution origins, providing 'technological fixes', such as hybrid seeds, improved inputs or mechanisation, for agricultural challenges.

The competition for donor support within the Research and Development context has led to increasing pressure for success stories of 'impact at scale' (CGIAR, 2015; Sumberg *et al.*, 2012a). The terminology of scaling is frequently used in a similar manner to the older connotations of 'diffusion of innovations' (Rogers, 2003). Despite a new name there remains a persisting struggle to apply non-linear approaches to scaling innovation, within the institutional environment of aiming for high impact targets, and quick need for results (Andersson & Sumberg, 2017; Glover *et al.*, 2016; Hall & Dijkman, 2019). These politics of this context have been the focus of the critical agronomy literature (Sumberg, 2017; Sumberg *et al.*, 2012b; Whitfield, 2015). This literature has critically reviewed some of the knowledge and institutional politics underpinning top-down innovation development, including donor driven agendas and the influence of philanthro-capitalism (Brooks, 2015). It outlines how agricultural technologies, such as SRI, CA or integrated pest management, emerge, become promoted within this political context (Sumberg *et al.*, 2013). For example, the changes in the agronomic research agenda as influenced by 1) neoliberalism, 2) the environmental movement, and 3) the participatory agenda (Sumberg *et al.*, 2013). This scholarship also scrutinizes the modes of communication and engagement in scaling agricultural innovations (e.g., Leeuwis & Van den Ban, 2004; Sumberg, 2017), and the effectiveness of the persistent popularity of theories of linear innovation diffusion.

The CA package has become part of the 'impact-at-scale' agenda of the CGIAR. Scaling fits within the idea of technological solutions that address challenges as long as they are distributed and used widely. This is a continuum from the Green Revolution or the New Green Revolution for Africa, with a focus on value chains, private-public partnerships and improved seeds, fertilisers and pesticides (Moseley, 2018). The founding donors of the CGIAR (and green revolution) are philanthropic donors from multinational corporations, which is also replicated in the Green Revolution for Africa, thus sustaining a capitalist agenda promoting consumption and growth (Brooks, 2015). In this respect, there remains a technical approach to agricultural innovation, supported by a business-oriented donor system embedded in neoliberalism and the notion of western agronomic knowledge as solution. The 'scale up source book' published in 2018 underlines this by stating in its executive summary: "it is essential to view agriculture as a business, not a social sector" (Cooley & Howard, 2018, p.vii). The growing involvement of business-oriented donors and Research and Development actors has resulted in the emphasis on growth and impact metrics needed to provide evidence and make a case for business (Glover *et al.*, 2016; Moseley, 2018).

The continuous push for CA as a response to various challenges, is manifested in the setting of CA adoption goals in Africa (e.g., Africa Congress on Conservation Agriculture in 2014). As part of the agricultural development agenda, 'scaling' is perceived as something that is desirable for contributing to the Sustainable Development Goals (SDG) (Schut *et al.*, 2020; Wigboldus *et al.*, 2016). CA is therefore presented as a form of farming that requires scaling to improve smallholder farmers' livelihoods in Africa, increase climate resilience, and reduce soil degradation. In this capacity, it is a part of several international agendas such as the SDGs, United Nations Framework Convention on Climate Change, the United Nations Convention to Combat Desertification (Mkomwa et al., 2017), and the Intergovernmental Panel on Climate Change (IPCC) special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (Mbow *et al.,* 2019; Jia *et al.*, 2019). Currently it is widely promoted in these international agendas under the banner of the FAO of the United Nations' (UN) Climate Smart Agriculture approach (Lipper *et al.*, 2018).

Within this Research and Development context, there is an ongoing process of technical construction of knowledge, defined by institutionalised scientific protocols. This technical construction of knowledge is characterised and critically analysed in Chapter 2.

1.3.2.2 Farm systems context

The concept of farm systems was introduced (Fresco & Westphal, 1988; Giller, 2013) to highlight the diversity and individuality of households within a farming system. Farmers may have widely different household dynamics including, resources, land management, livelihood and place within the community (Giller, 2013). These factors are dependent on socio-economic, agro-ecological, cultural, and institutional context. Outlining the diversity of farm systems indicates decision-making is not purely rational nor can it be grouped according to demographics.

On the concept of 'decision-making' there is a vast literary history, with particular contributions from economic theory on household decision-making as choices (Doss and Quisumbing, 2020). These contributions stress the rationality of decision-making with the aim to model this process, as used in linear diffusion theory (Rogers, 2003). Other scholars recognize the social and institutional influence on decision-making, arguing that decision-making is largely based on interactions (Leeuwis and Aarts, 2021). In the domain of household level decision-making, as is the case in this thesis' farm system context, the unitary model has been predominant (Doss and Quisumbing, 2020). In this model resources are pooled and individuals' preferences and production and consumption decisions are unified per household. Rejecting this model, the collective model, based on game theory, suggests that individuals within a household bargain over outcomes and decisions based on differed preferences or social norms (e.g. gender roles, power) (Doss and Quisumbing, 2020). Decision-making models like these have been developed for understanding the impact of interventions and their design, but are limited in using learnings from disciplines outside economics. In the CA debate, this challenge is apparent as the focus within farm system decision-making has been on the adoption or non-adoption outcome. This thesis argues and evidences that farm system decision-making goes beyond the adoption or non-adoption of CA (Chapter 4), and that farm systems' have different roles, identities (e.g. intersectional) and circumstances, which generate dynamic and multidimensional processes of decision-making.

From the farm systems perspective, critical literature has challenged the assumptions of linear diffusion and adoption, arguing that the process of technology scaling is more complex and dynamic (e.g., Leeuwis & Aarts, 2021; Sumberg, 2017; Wigboldus *et al.*, 2016). This complexity is especially apparent considering the variety in farm systems based on demographics, roles, contexts and identities. It affirms that innovations change and adapt across space and time through social learning and development (Figure 1.1). As package 'receivers', farmers interpret and evaluate the information and its fit with local knowledge, conditions, and systems (Glover *et al.*, 2017). The term local knowledge in this thesis is used the refer to all the related knowledge about the surroundings by people in an area (Trogrlić *et al.*, 2019) and is not static but can mix with scientific knowledge. Learning and knowledge production within the farm system can be based on various knowledges and perceptions, without formal methods of knowledge production. This process of multidirectional knowledge exchanges and learning with and among farm systems on CA as agricultural innovation is critically explored in Chapter 4.

1.3.2.3 Interaction space

This thesis aims in particular to understand how the space where these two social contexts interact shapes innovation, for example, through the exchange of knowledge about soil health. This interaction is often purposefully facilitated. There are various tools that exist in this space, such as farmer field schools and demonstration trials, as well as agricultural extension services. On-farm demonstration trials, for example, can adhere to research protocols set by Research and Development context but involve farmers as plot managers operating within a farm system (Maat & Glover, 2012; Wall *et al.*, 2019).

Each of these tools have been critically discussed in the literature in terms of their efficiency, impacts and structures (Anandajayasekeram *et al.*, 2007; Davis *et al.*, 2012; Niu & Ragasa, 2018). Extension research has increasingly moved from the concept of agricultural extension to framing it as communication of innovation, and its relation with knowledge and people (Leeuwis & Van den Ban, 2004). This conceptualizes extension as a socio-political issue as opposed to the often technical approach to extension (Cook *et al.*, 2021). Similarly, the dual role of on-farm demonstration trials and farmer field schools has been subject to discussion. In the case of CA on-farm trials, this dual role has been recognised as a conflict, between providing evidence and convincing the target audience of the new innovation (De Roo *et al.*, 2017). However, authors have argued about the potential selection biases (of participants and location) associated with trials and written critically about the research methods and the way in which this affects the validity of on-farm trial results for scaling agricultural innovation (De Roo *et al.*, 2017; Wall *et al.*, 2019). The way in which the interaction between the science and the farmers takes place therefore influences and forms the legitimacy of the dominant technical knowledge.

This thesis frames the on-farm demonstration trials as interaction spaces, making them a space of social and knowledge interaction in which power dynamics are shaped. As formulated by Henri Lefebvre (1991, p.24): “Space is a social product … it is not simply “there”, a neutral container waiting to be filled, but is a dynamic, humanly constructed means of control, and hence of domination, of power”. Based on this concept of space, the powercube framework, as introduced by Gaventa (2006) illustrates that power in interaction spaces can develop along three interrelated dimensions: 1) spaces as closed, invited or claimed, 2) forms of power as visible (i.e. observable decisions), hidden (i.e. agenda setting) and invisible (i.e. forming the meaning and acceptability) and 3) the levels as global, national and local. Placing and framing the on-farm demonstration trials in this way supports critically evaluating not only the technical construct of knowledge, but also the social and political forms of knowledge construction.

These constructed interaction settings provide farmers with an insight into, and an opportunity to engage with, the otherwise closed processes of research and development. However, the extent of this insight and engagement is dependent on the nature of the interaction space, which can both be closed and narrow, or open and wide. Closed and narrow interaction spaces are characterised by specific defined innovations, such as the defined CA package, and a focus on top-down 'teaching' (Ramisch, 2012). Based on the power cube framing, the opening of the space can have different forms, from 'invited' (e.g. when actors are invited by authority to participate, (Cornwall, 2002)) to 'claimed' (e.g. where non-authorities or less powerful actors claim or create the spaces based on common concerns (Cornwall, 2002)). A more open interaction space is created when focusing on two-way learning and flexible innovation packages in which spaces are used as tools to influence knowledge construction dynamics and simultaneously provide farmers with insights into the larger innovation system dynamics.

Previous studies have focused on how the information flow via these settings affects decision-making within farm systems. Khataza *et al.* (2018) found that lack of information was one of the three main factors for CA adoption decisions, the other two being low soil fertility and changes in natural environment. In particular, parameters such as farmers' knowledge transfer, extension access, and farmer group membership play a role in CA adoption. Studies such as Cofré-Bravo *et al*. (2019), have stressed the diverse configurations of knowledge and support networks, depending on farming aims, innovation wishes and livelihoods in shaping agricultural innovation. This implies that the reliance on the lead farmers or extension officer for agricultural innovation diffusion does not accommodate for this diverse process. However, a wide diversity of knowledge sources in the case of CA has also shown to lead to mixed messages (Fisher *et al.*, 2018). Additionally, how the information is delivered is important, some have suggested CA components should be introduced step by step and that greater participation is needed in the research activities and extension services (Brown *et al.*, 2019). Therefore, understanding the processes in the interaction space (Chapter 3) and how this shapes socio-technical change (Chapter 4) is pivotal for understanding innovation.

1.3.3 Dynamic interactions in the innovation landscape

As the institutions, interventions, and actors that make up the innovation landscape shift over time, so does the structure of the innovation landscape and the interaction space. There are many interdependencies within this process, for example scaling specific innovations are likely to lead to reduction in other practices (e.g., no tillage, or older maize varieties), or adaptation of practices due to social learning or experimentation (Glover, 2011; Leeuwis & Aarts, 2021). Depending on the social context relations over time, including interactions and trust among participants, certain knowledge discourses will be dominant. Historical legacies and decision-making can determine the current relations within the interaction space (Leeuwis & Aarts, 2021). For example, bad experiences with previous agricultural interventions or trials will lead to decreased trust in a new external intervention or agricultural innovation. This could lead to placing more trust in older and known practices over newly introduced practices where there was no involvement in the development. Equally, a good experience or trust relation can have the opposite effect. These dynamics will lead to the legitimisation or delegitimization of knowledge, resulting in different innovation processes. Innovation is a dynamic process shaped by how these interacting knowledges and relations evolve and change, over space and time (Figure 1.1). Throughout the empirical Chapters I aim to acknowledge and understand these dynamic interactions and processes using an interdisciplinary approach which acknowledges the technical as well as the social and political construct of knowledge. To illustrate the factors of time and historical context Chapter 4 uses descriptive qualitative case studies based on timeline drawings in interviews.

1.4 Case Study: Malawi

1.4.1 Malawi background

Malawi has been at the forefront of CA promotion in southern Africa since the late 1990s (Andersson & D'Souza, 2014). It is one of the southern African countries where CA has been argued to be favourable because of its low ruminant livestock density (i.e. low feeding demand on surface crop residue), high rural population density (i.e. labour availability, 83% of total population) and challenges with soil degradation (Asfaw *et al.*, 2018; Ngwira *et al.*, 2012a, 2012c; The World Bank, 2016a; Valbuena *et al.*, 2012). This makes it a suitable case study for understanding the CA and agricultural innovation scaling challenges and processes.

Malawi, located between latitude -9° and -18° S and 33° and 36°E in South Eastern Africa, has a sub-humid climate and is divided in three main regions, namely North, Central and Southern Malawi. The climate has three major seasons: May-August cool dry winter with average temperatures between 17°C and 27°C, hot dry period from September till October with temperatures up to 37°C and 50-80% humidity, and the wet season from November till April, covering 95% of the annual precipitation (Malawi Meteorological Services, 2020; Msowoya *et al.*, 2016).

Malawi has an estimated population of 18.6 million, growing at 2.64% per year (The World Bank, 2019). Agriculture provides approximately 35% to GDP and accounts for 61.41% of land allocation (Ngwira *et al.*, 2012a; Tesfaye *et al.*, 2015; The World Bank, 2016b). Malawi depends on rain-fed agriculture with maize being the major staple food crop, covering 80% of the cultivated land area and caloric intake (Ngwira *et al.*, 2012c, 2012a). Other major crops are groundnuts (*Arachis hypogaea L.*), tea (*Camellia sinensis (L.) Kuntze*), sugar (*Saccharum officinarum L.*), cassava (*Manihot esculenta Crantz*), coffee (*Coffea arabica L.*), tobacco (*Nicotiana tabacum L.*), and pigeonpea (*Cajanus cajan (L.) Millsp.*) and cowpea (*Vigna unguiculata L. Walp*) for intercropping in the south.

Due to challenges with population growth, declining landholding, deforestation, and soil erosion, climate change poses a significant threat to the agriculture-based economy, with the poverty headcount ratio national poverty line at 51.5% of the population (The World Bank, 2016c). Land is becoming severely degraded due to increasing population pressure and agricultural intensification. Soil loss, at a national rate of 29 ton/ha/yr, has been identified as a particular threat for agricultural development (Vargas & Omuto, 2016). Main human contributing factors are poor soil management (e.g., tillage, bare soils), cultivation on exposed steep slopes, low vegetation cover management, and insufficient implementation of policies on sustainable land management (Vargas & Omuto, 2016). This has resulted in decreases in soil fertility and soil depth for cultivation, agricultural productivity and increased focus on fertilizers (Vargas & Omuto, 2016).

The current common agricultural practices involve preparing the land manually with a hand hoe while residues are removed, burned or buried. Ridges are made annually approx. 75-90cm apart, on which the planting is applied (Fisher *et al.*, 2018). CA practices are promoted as new and an alternative for these ridge systems, but are similar to older local practices. These ridge systems practices result from colonial policy in southern Africa since the 1930s, which aimed to prevent soil degradation (Andersson & D'Souza, 2014). This is accompanied by a government focus on agricultural input support. Since 1970, Malawi has promoted 5 agricultural input programmes to support agricultural development (FAPDA FAO, 2015), with the last one (2006-present) being the Farm Input Subsidy programme (FISP), which is a voucher based subsidy for maize seed and fertilizer. The new government in 2020 announced in the National Assembly a redesign of the Affordable Inputs Programme (AIP) to provide seeds and fertilizer to all registered households and provide each farmer "a 50 Kgs bag of NPK; a 50 Kgs bag of Urea; either 5kgs of maize seed or 7 kgs of sorghum or 7kg of rice seed" (Government of Malawi (GoM), 2020: 3). Besides the central focus on input programmes, the government of Malawi also advocates for other approaches to stabilize and support food security and land management.

As part of the aim to improve sustainable land management CA has been promoted. In 1998, the NGO Sasakawa Global 2000 set up the first CA initiative, which was supported by the Malawian government (Dougill *et al.*, 2017; Thierfelder *et al.*, 2013). In this programme, CA adoption was incentivised through input packages. CA has been widely promoted as a way to improve maize production and drought resilience, by NGOs, government, international research centres and development. One of the major international research centres promoting and developing CA in Malawi is CIMMYT, as part of CGIAR. Initial CA advocacy took place without the development of a national strategy or guidelines, resulting in agreement about CA as an approved practice in 2013 and the formulation of National Guidelines for its promotion in 2016 through a National Conservation Agriculture Task Force (NCATF) (Dougill *et al.*, 2017). This agenda is still being promoted now. An increase of CA implementation was recorded from 65,000ha in 2013 to 211,000ha in 2015/2016 (Kassam *et al.*, 2015, 2019; The World Bank, 2016d), but recent estimates show that CA covers only 5.6% of the arable land in Malawi (Kassam *et al.*, 2019). The long history of CA promotion by Research and Development context drivers, soil degradation and climate change challenges, favourable high rural population and low livestock density, but low CA 'adoption' makes Malawi an ideal site for this study.

1.4.2 Study sites & agricultural intervention

The research was carried out in two communities in Malawi, Mwansambo in Nkhotakhota central Malawi and Lemu, Balaka in southern Malawi (Figure 1.2). These two communities are part of CIMMYT's on-farm trial network in southern Africa. This network was developed to gather evidence for CA performance (comparing it to local conventional practice) in various agro-ecological and socio-economic contexts. The trial funding comes from USAID funded Feed-the Future Project (Africa RISING) and the Gesellschaft for Internationale Zusammenarbeit (GIZ). The on-farm trials function as demonstration plots for the benefits of CA and 'train' the trial hosting farmers to become community advocates. The assumption is that this will lead to a snowballing of rational adoption decisions through local interactions and observations. The on-farm trials are a key component of the theory of change that drives the agricultural development agenda, namely the linear progression from demonstration plots and lead farmers to other community farmers. The context of long-term agricultural innovation intervention by a major international agricultural research institute provides a suitable context for the study objectives and approach.

Based on a field visit to 12 CIMMYT on-farm trial communities in Malawi in January – February 2018, Mwansambo and Lemu were selected to present two different agro-ecological zones, including different soil types and rainfall regimes (Table 1.1). Other factors such as altitude and temperature are similar which exclude interferences due to different biophysical factors. The two sites also provide a contrast in the socio-economic context. The distance to market is similar for both sites, but the population density, linearity majority and livestock density differ (Table 1.1).

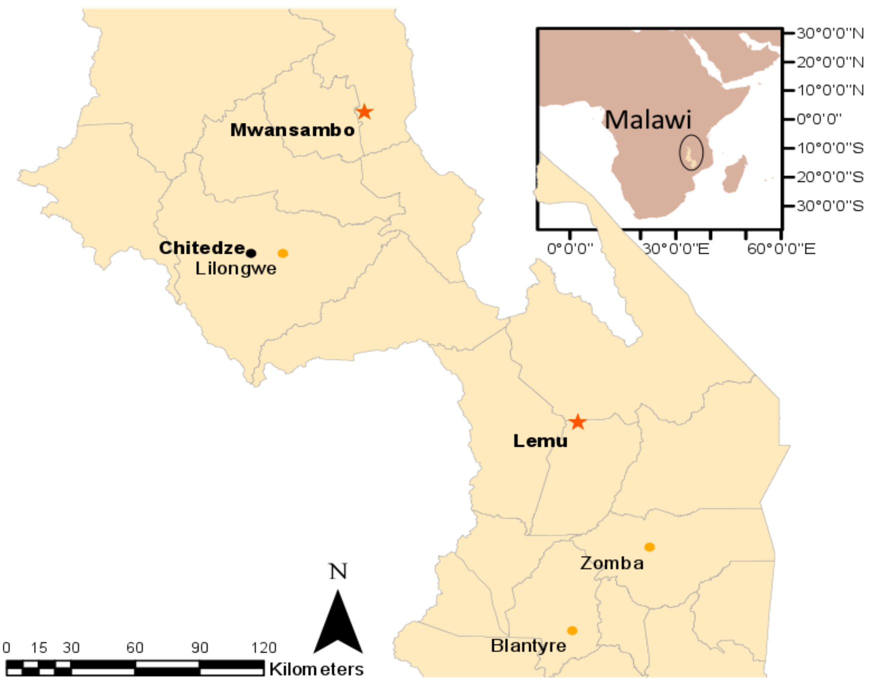

Figure 1.2 Malawi with the two communities which are the focus of this study: Mwansambo, Central Malawi and Lemu, Southern Malawi.

Table 1.1 Agro-ecological and socio-economic site characteristics.

Site Characteristics	**Site**	
	Mwansambo	**Lemu**
On-farm Trials	6	6
Latitude (°)	-13.32	-14.79
Longitude (°)	34.11	35.00
Altitude (masl)	665	735
Soil type	Haplic Lixisols	Chromic Luvisols
Soil Texture	Sandy Clay Loam	Sandy Loam
Rainfall (mm)	1330-1359	605-1226
Year CA started	2005	2007
Farming System	Maize mixed	Maize mixed
Land holding (ha)	0.5	0.4
Population	229,460 (71/km^2)	310,000 (145/km^2)
Distance to Market (km)	30	30
Extension	Total LandCare (TLC)	Machinga ADD (Gov)
Lineage Majority	Patrilineal	Matrilineal

Each community is host to 6 on-farm trials managed by farmers with support from extension officers. The on-farm trials in Mwansambo are supported by TLC, and the on-farm trials in Lemu are supported by Machinga Agricultural Development District (ADD). CIMMYT works together with these regional representatives, who are linked with community extension officers. In the case of Mwansambo, there is both a government extension officer and TLC extension officer, whereas in Lemu there is only a government extension officer.

Each on-farm trial has three main treatments as described previously by Ngwira *et al.* (2012c) and Thierfelder *et al.* (2015b). The treatments are as follows:

1) Conventional practice with ridge and furrow system (CP) prepared with a hand hoe in September or October with crop residues removed after harvest.
2) Conservation agriculture with sole maize (CAM). In this treatment there is no tillage and maize (*Zea mays*) is planted with a dibble stick (one hole for seed and one for fertilizer). Residues are retained as surface mulch.
3) Conservation agriculture with maize and legume intercrop (CAML): cowpea (*Vigna unguiculata L.*) in Mwansambo and pigeon pea (*Cajanus Cajan L.*) in Lemu. Crops are planted with a dibble stick and have similar no tillage and crop residue treatment as CAM.

All plots are rotated annually with groundnuts (*Arachis hypogaea L.)* planted on ridges in CP and on the flat in CAM and CAML. For all treatments, ridge spacing was constant at 75cm between maize rows and 25cm between planting stations with one seed planted per station. In the maize-legume intercrop, pigeon pea (Lemu) and cowpea (Mwansambo) were planted between maize lines at 60cm and 40cm spacing respectively. All treatments received similar fertilizer application rates of 69kg N ha^{-1}, which was applied in two stages: 100kg ha^{-1} of N:P:K (23:21:0+4S) during seeding and 100kg ha^{-1} of urea (46% N) approximately three weeks after crop emergence. Weeding is done manually with a hand hoe in the CP treatment at different times during the cropping season and ridges are reformed during this process (the operation is locally called 'banking'). To control weeds in the CA treatments, a mixture of 2.5 L ha^{-1} glyphosate (N-(phos-phono-methyl) glycine), Harness® (acetochlor (2-ethyl-6-methylphenyl-d11)) (Mwansambo) or Bullet® (Lemu) (25.4% Alachlor (2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl) acetamide) and 14.5% atrazine (2-Chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine)) was applied. Additional manual hoe weeding was advised as soon as weeds reached 10 cm height or 10 cm in circumference.

1.5 Research Design

1.5.1 Interdisciplinary approach

Farming Systems Research (FSR) emerged in the 70s and 80s as a way of approaching the dynamic interactions that characterise the farm system, emphasising the value of interdisciplinary 'on-farm research' and 'farmer-oriented research' (Whitfield *et al.*, 2015). It emphasized the importance of giving space to the lived experiences, and the influence of interconnected socio-economic, agro-ecological, political and institutional context (Leach *et al.*, 2010; Scoones, 2009).

Associated with FSR, participatory methods, such as participatory rural appraisals (Chambers, 1981, 1994; Chambers *et al.*, 1989), became central as a way to emphasize the importance of local experience, and voices (Richards, 1985; Warren, 1991). It aimed to make the 'people' central within development approaches through including the people affected by the intervention who previously had little influence or ownership in this process (also termed 'marginalized people'). It provided an alternative to donor-driven and outsider narratives and was quickly adopted by organisations under the banner of improving 'empowerment, sustainability, and relevance'. These participatory approaches especially opened up new approaches in development and natural science, leading to participatory environmental modelling (Turreira-garcía *et al.*, 2018) and ecological and soil health studies focused on including local knowledge and indicators (Mairura *et al.*, 2007; Prudat *et al.*, 2018; Reed *et al.*, 2008).

However, participatory approaches have also been subject to critique (Cooke & Kothari, 2001; Mosse, 1994). Cooke and Kothari (2001: 7-8) describe participation as tyranny in three ways: "1) tyranny of decision-making and control: Do participatory facilitators override existing legitimate decision-making processes? 2) tyranny of the group: Do group dynamics lead to participatory decisions that reinforce the interest of the already powerful? 3) tyranny of methods: Have participatory methods driven out other methods which have advantages participation cannot provide?" (Cooke & Kothari, 2001: 7–8). Participatory methods, such as those applied within soil sciences, can support the understanding of how innovation takes place within farm systems from local perspectives, but does require reflection on the positionality and impact of these methods. Chapter 3 critically discusses an integrated soil health assessment approach including participatory elements to feature the farm system experience and knowledge interactions of soil health. However, Chapter 3 and Chapter 4 use various methods and triangulation to balance the methodological pitfalls, and these are further reflected on in Chapter 5.

Despite the FSR movement, the dominant literature on CA innovation favours a techno-scientific approach to knowledge construction, as is highlighted in Chapter 2. As a response to this, a more integrated and cross-disciplinary approach to studying innovation can take a variety of forms. Firstly, knowledges can be studied via natural and social sciences, each highlighting different aspects of agricultural innovation. A focus on this disciplinary integration has been called scientific integration, and forms an interdisciplinary approach (Figure 1.3) (Mauser *et al.*, 2013; Tress *et al.*, 2005). In addition there is a sectoral integration based on the participation of non-academic stakeholders leading to participatory approaches (Figure 1.3) (Mauser *et al.*, 2013; Tress *et al.*, 2005). The combination of scientific and sectoral integration is called transdisciplinary (Figure 1.3) (Mauser *et al.*, 2013; Tress *et al.*, 2005). Transdisciplinary research is described with key characteristics of: 1) focus on real world challenges 2) iterative and reflective cycles 3) involvement and integration of stakeholders' perspectives (Lang *et al.*, 2012; Russell *et al.*, 2008). Whereas a transdisciplinary approach would be an ultimate integration of knowledges, there are limitations in the feasible level of participation within the context and positionality of this study, which will be critically discussed and reflected on in Chapter 5. This thesis addresses the challenges of multidimensional and dynamic approaches by using an interdisciplinary approach with participatory elements, including iterative cycles and reflection, to capture different values, knowledges, and dynamic interactions in the agricultural innovation process.

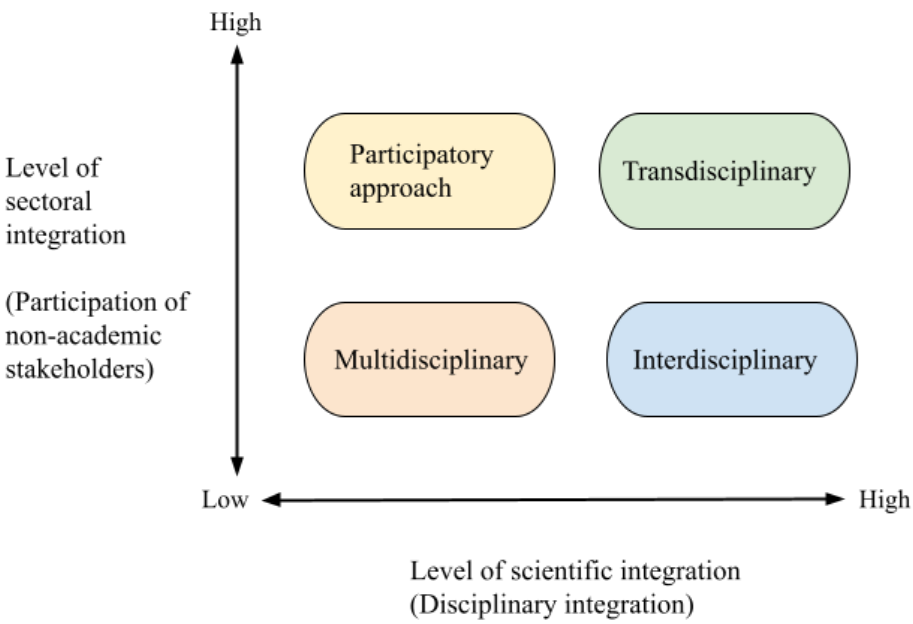

Figure 1.3 Categories of levels of sectoral or scientific integration, based on Tress et al. 2005 and Mauser et al. 2013

Conceiving of agricultural innovation as a process of knowledge construction by multiple actors and institutions, means that we must also accept that innovation is not an objective topic of study. To capture the subjectivity of the innovation process, an interdisciplinary approach comprising of multiple perspectives and methods, can provide a more holistic view of agricultural innovation scaling processes and decision-making in the farm system. As a part of this, participatory elements are employed to emphasize the local experience of innovation within the farm system. Learning and negotiating across these knowledges is important for understanding how the innovation processes flow across the innovation landscape with various actors. Based on this approach, Chapter 5 critically reflects on the variety of methodological applications and how they complement each other.

In applying an interdisciplinary approach, for the work in Chapter 3 and 4, I became both a facilitator and observer of innovation processes. Facilitator in terms of organizing the coming together of people, knowledge and perspective. In this role, I became part of the innovation process and knowledge production through the application of interdisciplinary and participatory methods which also received feedback. At the same time, I held the role of observer of the knowledge exchange that was taking place. Here I focused on understanding the processes that take place without my direct involvement. From this point of view, I reflected on the extent of interdisciplinarity and participation within agricultural research for development. Observing the processes on agricultural innovation in the farm system and across the innovation landscapes included both of these roles, and required continuous reflection on my positionality, which I reflect on in the discussion chapter.

1.5.2 Methods

Using an interdisciplinary approach means applying methods that are grounded in different disciplines (Figure 1.4). Firstly, a realist systematic review was used to understand disciplinary approaches in current literature. The empirical insights are based on various fieldwork visits, starting with a scoping trip visiting CIMMYT trial communities in Zambia and Malawi in January and February 2018. The first month long fieldwork visit to Mwansambo and Lemu took place from 30th of September 2018 till 22nd of October 2018. This was oriented around obtaining local permissions and support, and conducting focus groups and participatory rural appraisals including labour calendars, timelines and ranking exercises. One focus group was held with trial farmers (6 farmers) and 2 focus groups with non-trial farmers (8–10 farmers) for each community. Furthermore, participatory soil moisture sampling and transect walks were piloted to test methods and form ideas for integrated soil health evaluation.

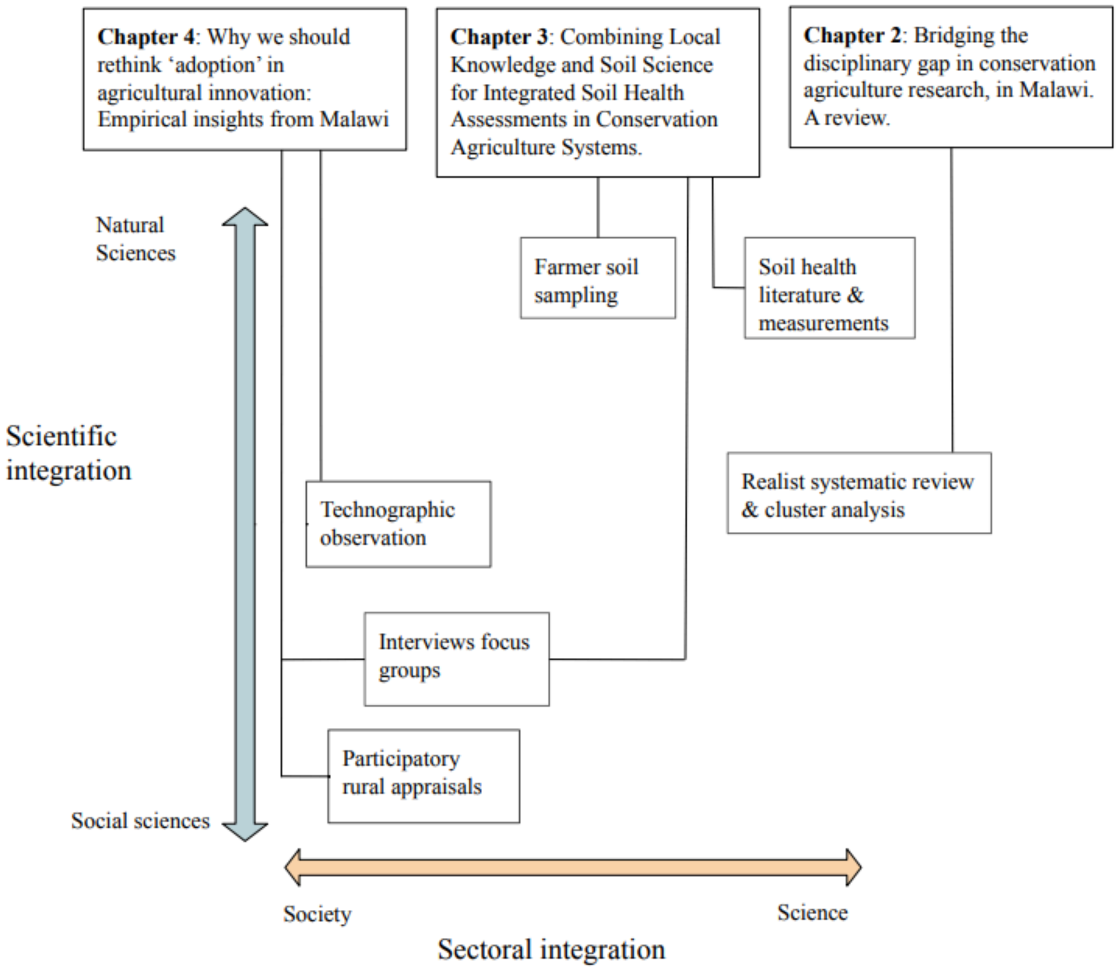

Figure 1.4 Conceptual graph showing the position of interdisciplinary methods used within this thesis in relation to the scientific and sectoral integration. Based on concepts of integration by Mauser et al. 2013

The majority of the data was collected during a 3-month field visit during the rainy season from 19th of January 2019 till the 14th of April 2019. Based on the experience with focus groups and participatory rural appraisals, I decided that individual semi structured interviews would be more appropriate for gaining an in depth understanding of the diversity of farm contexts and would reduce group pressure and dynamics. Within each interview, field mapping was used to discuss current agricultural practices. This was followed by drawing a timeline of agricultural changes, which was used to discuss the reasoning behind these changes. It was also applied to avoid bias of decision-making in the particular wet season during this fieldwork (Cyclone Idai and national flooding emergency). Lastly, agricultural innovation knowledge sources were discussed and drawn on a graph with 'knowledge' and 'influence' axes, to discuss the importance and role of different actors in the innovation landscape. In total 6 trial farmers and 12-14 farmers with different relations to the trials were interviewed in each community. This was accompanied by technographic (i.e. ethnography of technology-in-use as methodological approach) observations and informal conversation with farmers, neighbours and the extension officers during my time living within the area during all fieldwork visits. During my stay, there were also field day visits from the CIMMYT, TLC and government team, as on-farm trial drivers, which I attended. The extension officer was the main point of contact at the start of the fieldwork and later on farmers were approached directly, with only occasional liaison and feedback conversations with the extension officer. The triangulation between these methods informed the rethinking of 'adoption' and scaling discussed in Chapter 4, and part of the farmer observations on soil health for Chapter 3.

To understand the role of soil health in farmer-decision making, the focus of Chapter 3, the interviews also covered questions on soil health indicators and any observations of soil impact due to the practices of tillage/no-tillage, mulching, or crop diversification. Trial farmer focus groups were invited at the start to discuss the soil health indicators that would be measured on the on-farm trials. The following soil health indicators were measured on the on-farm trials for each treatment: soil carbon, total nitrogen, nitrate/nitrite, ammonium, infiltration, moisture, structure, bulk density and maize yield. Farmers participated in the field measurements of soil nitrogen, soil infiltration, moisture, soil structure and bulk density. The specific measurement method for each soil health indicator can be found in Chapter 3. At the end of the soil sampling, another focus group with trial farmers was organized to discuss preliminary results, and gather feedback from their experience and perspectives on this work and method. The plan was to return in July 2020 to further discuss carbon and nitrogen soil results, which required lab processing, and discuss soil health results with trial farmers and reflect further on the communication processes of on-farm trials, but this had to be postponed due to Covid-19 travel restrictions.

Focus groups and interviews were recorded and translated with the support of a Malawian assistant, who was an outsider to the Mwansambo and Lemu region. I learnt basic Chichewa sentences and words to cross check and follow and participate in conversations. Notes were taken during the interviews and focus groups and cross checked with recordings, drawings and interpretations by the research assistant. Triangulation of methods was used to validate the meaning of translations.

Further methodological description and justification is provided in each chapter, as this thesis is submitted in published paper format.

1.5.3 Research ethics

Human participation was involved in Chapter 3 and 4. Ethical consent was obtained from the Environment Faculty Research Ethics Committee at the University of Leeds (AREA 17-147) and Lilongwe University of Agriculture and Natural Resources. Written consent was asked from participants for both the focus groups and interviews. Participants were given verbal or written information on the aim, involvement, benefits and risks of the research. Pilot visits were conducted to improve my understanding of the context, language and appropriate research approaches, and I reflect on this in Chapter 5. Pseudonyms have been applied to anonymize the participant identities for Chapter 4 and no names have been used for Chapter 3.

1.6 Thesis Structure

The thesis is structured in 3 empirical chapters, Chapter 2 analyses approaches taken to evaluate and 'measure' agricultural innovation. This highlights the presence of a dominant techno-scientific approach to the study of CA innovation, and subsequently critically evaluates the extent to which interdisciplinarity is currently adopted in agricultural innovation research. It argues that that incomplete knowledge exists in the gaps between disciplines. This systematic review involves a literature cluster analysis to identify the dominant knowledge approaches. Articles were analysed on the basis of how they conceive of: (1) what CA is (i.e. how CA practices are defined and described), (2) what it means to work (i.e. how CA success is defined and measured), (3) where and for whom it works (i.e. the contextual and determinant factors of success that are considered) and (4) why it works (i.e. the explanatory mechanisms for success in particular contexts that are presented). Qualitative coding based on a grounded theory approach was used to address the four dimensions (Glaser & Strauss, 1967). It shows that the current studies represent two distinct approaches to the question 'what forms of CA work, where, and why?', namely agro-ecological and socio-economic and that neither of these approaches can address the full scope of this question alone, the result is that there are particular gaps in understanding 'why' CA works in some contexts and not others.

Chapter 3 focuses on an analysis of the interaction space between agricultural research for development institutions and farmers. This is done through a novel stepwise framework within the CA discourse, drawing on natural and social science methods for analysing CA's impact on soil health in farm systems. A stepwise interdisciplinary framework is presented, involving: (1) discussing soil health impact with farmers; (2) identifying and comparing farmer and literature soil health indicators, (3) taking soil measurements (of indicators) with the help of farmers; (4) discussing soil measurements results and farmer observations. Farmers' soil health indicators were identified as crop performance, soil consistency, moisture content, erosion, colour and structure. These local indicators were consistent with conventional soil health indicators for quantitative measurements. Soil measurements and observations show that CA leads to soil structural change, including soil moisture and infiltration. Farmers perceive ridges as positive due to aeration, nutrient release and infiltration, which corresponds with higher recorded exchangeable ammonium, and nitrate/nitrite. This perspective contributes to the continued popularity of ridges, despite higher yield and total nitrogen measurements under CA. The perceived carbon benefits of residues, and ridge advantages have encouraged farmers to bury residues in ridges. This work shows that an integrated approach provides more nuanced and localized knowledge about land management.

Chapter 4 is grounded in farm systems research and aims to understand how knowledge is constructed within and beyond the interaction space. It highlights how the assumed linear diffusion model for agricultural innovation plays out on the ground in the complex contexts of farm systems, showing that it not as linear and effective as assumed. In particular I argue that innovation within farm systems is shaped by: (1) s*ocial dynamics & information transfer, (2) contextual cost and benefits*, *(3) experience & risk aversion,* and *(4) practice adaptation.* It is further argued that social dimensions, including dynamics between actors, and institutions highly affect farmer decision-making. Moving beyond the binary distinctions between adoption/non-adoption, the chapter highlights a wide diversity of adaptations and re-inventions of CA. Building from these insights, I considers how innovation scaling can be achieved while acknowledging the multidimensionality and diversity of farm systems.

The fifth chapter critically discusses both the empirical insights on the technical, social and political construct of knowledge, including what this means for defining ‘successful agricultural innovation’. Here I also discuss the methodological interdisciplinary approach with particular attention to positionality, ‘participation’, and project relations, such as the role of observer and facilitator in the knowledge construction process. The chapter closes with a critical evaluation of the implication of this work for agricultural innovation, the innovation landscape and the interaction space.

References

Anandajayasekeram P, Davis KE, Workneh S. 2007. Farmer Field Schools: An Alternative to Existing Extension Systems? Experience from Eastern and Southern Africa. 14. DOI: 10.5191/jiaee.2007.14107

Andersson J, Sumberg J. 2017. Knowledge politics in development-oriented agronomy. In: Sumberg J (ed) *Agronomy for Development: The Politics of Knowledge in Agricultural Research*. Routledge : Abingdon, Oxon

Andersson JA, D’Souza S. 2014. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment* 187: 116–132. DOI: 10.1016/j.agee.2013.08.008

Andersson JA, Giller KE. 2012. On heretics and God ’ s blanket salesmen : Contested claims for Conservation Agriculture and the politics of its promotion in African smallholder farming. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World*. Earthscan, Routledge: Abingdon, Oxon, 22–46. DOI: 10.4324/9780203125434

Asfaw S, Orecchia C, Pallante G, Palma A. 2018. *Soil and nutrients loss in Malawi: an economic assessment.* , 1–88

Bates MJ. 2005. Information and knowledge: An evolutionary framework for information science. *Information Research* **10**

Baudron F, Tittonell P, Corbeels M, Letourmy P, Giller KE. 2011. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. *Field Crops Research* 132: 117–128. DOI: 10.1016/j.fcr.2011.09.008

Brooks S. 2015. Philanthrocapitalism, 'pro-poor' agricultural biotechnology and development. *New Philanthropy and Social Justice: Debating the Conceptual and Policy Discourse*, 101–114. DOI: 10.2307/j.ctt1t89dwz.11

Brown B, Llewellyn R, Nuberg I. 2018a. Why do information gaps persist in African smallholder agriculture? Perspectives from farmers lacking exposure to conservation agriculture. *Journal of Agricultural Education and Extension* 24: 191–208. DOI: 10.1080/1389224X.2018.1429283

Brown B, Nuberg I, Llewellyn R. 2017. Negative evaluation of conservation agriculture: perspectives from African smallholder farmers. *International Journal of Agricultural Sustainability* 15: 467–481. DOI: 10.1080/14735903.2017.1336051

Brown B, Nuberg I, Llewellyn R. 2018b. Constraints to the utilisation of conservation agriculture in Africa as perceived by agricultural extension service providers. *Land Use Policy* 73: 331–340. DOI: 10.1016/j.landusepol.2018.02.009

Brown B, Nuberg I, Llewellyn R, Com BB. 2019. From interest to implementation: exploring farmer progression of conservation agriculture in Eastern and Southern Africa. *Environment, Development and Sustainability*. DOI: 10.1007/s10668-019-00340-5

CGIAR. 2015. *CGIAR Strategy and Results Framework 2016-2030.*

Chambers R. 1981. *Rapid rural appraisal: rationale and repertoire'. Public Administration And Development*

Chambers R. 1994. The Origins and Practice of Participatory Rural Appraisal. *World Development* 22: 953–969. DOI: 10.1016/0305-750X(94)90141-4

Chambers R, Pacey A, Thrupp LA. 1989. *Farmer First: Farmer Innovation and Agricultural Research*. Intermediate Technology Publications: London, UK

Cheesman S, Thierfelder C, Eash NS, Kassie GT, Frossard E. 2016. Soil carbon stocks in conservation agriculture systems of Southern Africa. *Soil and Tillage Research* 156: 99–109. DOI: 10.1016/j.still.2015.09.018

Chinseu E, Dougill A, Stringer L. 2019. Why do smallholder farmers dis-adopt conservation agriculture? Insights from Malawi. *Land Degradation and Development* 30: 533–543. DOI: 10.1002/ldr.3190

Cleaver F, Koning J de. 2015. Furthering critical institutionalism. *International Journal of the Commons* **9**: 1–18. DOI: 10.18352/IJC.605

Cofré-Bravo G, Klerkx L, Engler A. 2019. Combinations of bonding, bridging, and linking social capital for farm innovation: How farmers configure different support networks. *Journal of Rural Studies* 69: 53–64. DOI: 10.1016/j.jrurstud.2019.04.004

Cook BR, Satizábal P, Curnow J. 2021. Humanising agricultural extension: A review. *World Development* 140: 105337. DOI: 10.1016/j.worlddev.2020.105337

Cooke B, Kothari U. 2001. Participation: the New Tyranny? *International Journal of Educational Development.* Zed Books: London, UK

Cooley L, Howard J. 2018. *Scale Up Sourcebook*. Indiana, USA

Corbeels M, de Graaff J, Ndah HT, Penot E, Baudron F, Naudin K, Andrieu N, Chirat G, Schuler J, Nyagumbo I, Rusinamhodzi L, Traore K, Mzoba HD, Adolwa IS. 2014. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture, Ecosystems & Environment* 187: 155–170. DOI: 10.1016/j.agee.2013.10.011

Corbeels M, Naudin K, Whitbread AM, Kühne R, Letourmy P. 2020. Limits of conservation agriculture to overcome low crop yields in sub-Saharan Africa. *Nature Food* 1: 447–454. DOI: 10.1038/s43016-020-0114-x

Cornwall A. 2002. Making spaces, changing places: situating participation in development. *IDS Working Paper 170* **170**: 1–43. DOI: 10.1126/science.1061967

Davis K, Nkonya E, Kato E, Mekonnen DA, Odendo M, Miiro R, Nkuba J. 2012. Impact of Farmer Field Schools on Agricultural Productivity and Poverty in East Africa. *World Development* 40: 402–413. DOI: 10.1016/j.worlddev.2011.05.019

De Roo N, Andersson JA, Krupnik TJ. 2017. on-Farm Trials for Development Impact? the Organisation of Research and the Scaling of Agricultural Technologies. *Experimental Agriculture* 1–22. DOI: 10.1017/S0014479717000382

Doss CR, Quisumbing AR. 2020. Understanding rural household behavior: Beyond Boserup and Becker. *Agricultural Economics (United Kingdom)* **51**: 47–58. DOI: 10.1111/agec.12540

Dougill AJ, Whitfield S, Stringer LC, Vincent K, Wood BT, Chinseu EL, Steward PR, Mkwambisi D. 2017. Mainstreaming conservation agriculture in Malawi: Knowledge gaps and institutional barriers. *Journal of Environmental Management* 195: 25–34. DOI: 10.1016/j.jenvman.2016.09.076

Eze S, Dougill AJ, Banwart SA, Hermans TDG, Ligowe IS, Thierfelder C. 2020. Impacts of conservation agriculture on soil structure and hydraulic properties of Malawian agricultural systems. Soil and Tillage Research 201: 104639. DOI: 10.1016/j.still.2020.104639

FAO. 2008. *Investing in sustainable agricultural intensification. The role of conservation agriculture*. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAPDA FAO. 2015. *Country Fact Sheet on Food and Agriculture Policy Trends*. Rome

Fisher M, Holden ST, Thierfelder C, Katengeza SP. 2018. Awareness and adoption of conservation agriculture in Malawi: what difference can farmer-to-farmer extension make? *International Journal of Agricultural Sustainability* 16: 310–325. DOI: 10.1080/14735903.2018.1472411

Fresco LO, Westphal E. 1988. A Hierarchical Classification of Farm Systems. *Experimental Agriculture* 24: 399–419. DOI: 10.1017/s0014479700100146

Gaventa J. 2006. Finding the Spaces for Change: A Power Analysis. *IDS Bulletin* **37**: 23–33

Giller KE. 2013. Guest editorial: Can we define the term “farming systems”? A question of scale. *Outlook on Agriculture*, 149–153. DOI: 10.5367/oa.2013.0139

Giller KE, Andersson JA, Corbeels M, Kirkegaard J, Mortensen D, Erenstein O, Vanlauwe B. 2015. Beyond conservation agriculture. *Frontiers in Plant Science* 6: 1–14. DOI: 10.3389/fpls.2015.00870

Giller KE, Witter E, Corbeels M, Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics’ view. *Field Crops Research* 114: 23–34. DOI: 10.1016/j.fcr.2009.06.017

Glaser BG, Strauss AL. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research*. Aldine Transaction: New Brunswick, USA. DOI: 10.2307/2094063

Glover D. 2011. The System of Rice Intensification: Time for an empirical turn. *NJAS - Wageningen Journal of Life Sciences* 57: 217–224. DOI: 10.1016/j.njas.2010.11.006

Glover D, Sumberg J, Andersson JA. 2016. The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. *Outlook on Agriculture* 45: 3–6. DOI: 10.5367/oa.2016.0235

Glover D, Venot JP, Maat H. 2017. On the movement of agricultural technologies: Packaging, unpacking and situated reconfiguration. *Agronomy for Development: The Politics of Knowledge in Agricultural Research*, 14–30. DOI: 10.4324/9781315284057

Government of Malawi (GoM). 2020. *Ministerial statement on the affordable inputs programme.* Lilongwe, Malawi

Hall AJ, Dijkman J. 2019. *Public Agricultural Research in an Era of Transformation : The Challenge of Agri-Food System Innovation.* 1: 67

Holden ST, Fisher M, Katengeza SP, Thierfelder C. 2018. Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land Use Policy* 76: 113–123. DOI: 10.1016/j.landusepol.2018.04.048

IAASTD. 2009. *International Assessment of Agricultural Knowledge, Science and Technology for Development. Global report*. Island Press: Washington, D.C.

Kassam A, Friedrich T, Derpsch R. 2019. Global spread of Conservation Agriculture. International *Journal of Environmental Studies* 76: 29–51. DOI: 10.1080/00207233.2018.1494927

Kassam A, Friedrich T, Derpsch R, Kienzle J. 2015. Overview of the Worldwide Spread of Conservation Agriculture. *Field Actions Science Reports* 8

Khataza RRB, Doole GJ, Kragt ME, Hailu A. 2018. Information acquisition, learning and the adoption of conservation agriculture in Malawi: A discrete-time duration analysis. *Technological Forecasting and Social Change* 132: 299–307. DOI: 10.1016/J.TECHFORE.2018.02.015

Kristjanson P, Bryan E, Bernier Q, Twyman J, Meinzen-Dick R, Kieran C, Ringler C, Jost C, Doss C. 2017. Addressing gender in agricultural research for development in the face of a changing climate: where are we and where should we be going? *International Journal of Agricultural Sustainability* **15**: 482–500. DOI: 10.1080/14735903.2017.1336411

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ. 2012. Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science* 7: 25–43. DOI: 10.1007/s11625-011-0149-x

Leach M, Stirling A, Scoones I. 2010. *Dynamic sustainabilities: technology, environment, social justice.* Earthscan, Routledge: Abingdon, Oxon

Leeuwis C, Aarts N. 2021. Rethinking Adoption and Diffusion as a Collective Social Process: Towards an Interactional Perspective. In: Campos H (ed) *The Innovation Revolution in Agriculture*. Springer International Publishing: Switzerland, 95–116. DOI: 10.1007/978-3-030-50991-0

Leeuwis C, Schut M, Klerkx L. 2018. Systems Research in the CGIAR as an Arena of Struggle. In: Sumberg J (ed) *Agronomy for Development.* Routledge: Abingdon, Oxon, 59–78. DOI: 10.4324/9781315284057-5

Leeuwis C, Van den Ban A. 2004. *Communication for Rural Innovation Rethinking Agricultural Extension*. Blackwell Science Ltd: Oxford, UK. DOI: 10.1002/9780470995235

Lefebvre H. 1991. *The Production of Space*. Wiley-Blackwell: Oxford, UK

Ligowe IS, Cleoups Nalivata P, Njoloma J, Makumba W, Thierfelder C. 2017. Medium-term effects of conservation agriculture on soil quality. *African Journal of Agricultural Research* 12: 2412–2420. DOI: 10.5897/AJAR2016.11092

Lipper L, McCarthy N, Zilberman D, Asfaw S, Branca G. 2018. *Climate Smart Agriculture - Building Resilience to Climate Change.* Springer Nature: Cham, Switzerland. DOI: 10.1007/978-3-319-61194-5

Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen PT, Sessa R, Shula R, Tibu A, Torquebiau EF. 2014. Climate-smart agriculture for food security. *Nature Climate Change* 4: 1068–1072. DOI: 10.1038/nclimate2437

Lobell DB, Bänziger M, Magorokosho C, Vivek B. 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature Climate Change* 1: 42–45. DOI: 10.1038/nclimate1043

Maat H, Glover D. 2012. Alternative Configurations of agronomic experimentation. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World.* Routledge: Abingdon, Oxon, 131–145

Mairura FS, Mugendi DN, Mwanje JI, Ramisch JJ, Mbugua PK, Chianu JN. 2007. Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya. *Geoderma* 139: 134–143. DOI: 10.1016/j.geoderma.2007.01.019

Malawi Meteorological Services. 2020. *Climate of Malawi.*

Mauser W, Klepper G, Rice M, Schmalzbauer BS, Hackmann H, Leemans R, Moore H. 2013. Transdisciplinary global change research: The co-creation of knowledge for sustainability. *Current Opinion in Environmental Sustainability.* Elsevier, 420–431. DOI: 10.1016/j.cosust.2013.07.001

Mbow C, Rosenzweig C, Barioni LG, Benton TG, Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner H-O, Roberts DC, Zhai P, Slade R, Connors S, Van Diemen R, Ferrat M, Haughey E, Luz S, Neogi S, Pathak M, Petzold J, Pereira JP, Vyas P, Huntley E, Kissick K, Belkacemi M, Malley J. 2019. Food security . In: Shukla PR, Skea J, Calvo Buendia E, Masson-Delmotte V, Pörtner HO, Roberts DC, Zhai P, Slade R, Connors S, van Diemen R, Ferrat M, Haughey E, Luz S, Neogi S, Pathak M, Petzold J, Portugal Pereira J, Vyas P, Huntley E, Kissick K, Belkacemi M and Malley J (eds) *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*

Mloza-Banda HR, Makwiza CN, Mloza-Banda ML. 2016. Soil properties after conversion to conservation agriculture from ridge tillage in Southern Malawi. *Journal of Arid Environments* 127: 7–16. DOI: 10.1016/j.jaridenv.2015.11.001

Mloza-Banda ML, Cornelis WM, Mloza-Banda HR, Makwiza CN, Verbist K. 2014. Soil properties after change to conservation agriculture from ridge tillage in sandy clay loams of mid-altitude Central Malawi. *Soil Use and Management* 30: 569–578. DOI: 10.1111/sum.12139

Moseley WG. 2018. One Step Forward, Two Steps Back in Farmer Knowledge Exchange. In: Sumberg J (ed) *Agronomy for Development.* Routledge: Abingdon, Oxon , 79–90. DOI: 10.4324/9781315284057-6

Mosse D. 1994. Authority, Gender and Knowledge: Theoretical Reflections on the Practice of Participatory Rural Appraisal. *Development and Change* 25: 497–526. DOI: 10.1111/j.1467-7660.1994.tb00524.x

Msowoya K, Madani K, Davtalab R, Mirchi A, Lund JR. 2016. Climate Change Impacts on Maize Production in the Warm Heart of Africa. *Water Resources Management* 30: 5299–5312. DOI: 10.1007/s11269-016-1487-3

Ndah HT, Probst L, Kaweesa S, Kuria P, Mkomwa S, Rodrigues P, Basch G, Uckert G, Sieber S, Knierim A, Zander P, Schuler J. 2020. Improving farmers' livelihoods through conservation agriculture: options for change promotion in Laikipia, Kenya. *International Journal of Agricultural Sustainability* 18: 212–231. DOI: 10.1080/14735903.2020.1746063

Ngwira AR, Aune JB, Mkwinda S. 2012a. On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research* 132: 149–157. DOI: 10.1016/j.fcr.2011.12.014

Ngwira AR, Aune JB, Thierfelder C. 2014a. DSSAT modelling of conservation agriculture maize response to climate change in Malawi. *Soil and Tillage Research* 143: 85–94. DOI: 10.1016/j.still.2014.05.003

Ngwira AR, Johnsen FH, Aune JB, Mekuria M, Thierfelder C. 2014b. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. *Journal of Soil and Water Conservation* 69: 107–119. DOI: 10.2489/jswc.69.2.107

Ngwira AR, Sleutel S, de Neve S. 2012b. Soil carbon dynamics as influenced by tillage and crop residue management in loamy sand and sandy loam soils under smallholder farmers' conditions in Malawi. *Nutrient Cycling in Agroecosystems* 92: 315–328. DOI: 10.1007/s10705-012-9492-2

Ngwira AR, Thierfelder C, Lambert DM. 2012c. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems* 28: 350–363. DOI: 10.1017/S1742170512000257

Niang I, Ruppel OC, Abdrabo MA, Essel A, Lennard C, Padgham J, Urquhart P. 2014. Part B : Regional Aspects. *Climate Change 2014: Impacts, Adaptation and Vulnerability - Contributions of the Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, United Kingdom and New York, NY, USA, 1199–1265. DOI: 10.1017/CBO9781107415386.002

Niu C, Ragasa C. 2018. Selective attention and information loss in the lab-to-farm knowledge chain: The case of Malawian agricultural extension programs. *Agricultural Systems* 165: 147–163. DOI: 10.1016/j.agsy.2018.06.003

North D. 1990. *Institutions, institutional change, and economic performance*. Cambridge University Press: Cambridge, United Kingdom

Ostrom E. 2011. Background on the Institutional Analysis and Development Framework. *Policy Studies Journal* **39**: 7–27. DOI: 10.1111/J.1541-0072.2010.00394.X

Palombi I, Sessa R. 2013. *Climate-Smart Agriculture Sourcebook. Sourcebook on Climate-Smart Agriculture, Forestry and Fisheries.* Food and Agriculture Organization of the United Nations. DOI: 10.1080/03068374.2014.874687

Powlson DS, Stirling CM, Thierfelder C, White RP, Jat ML. 2016. Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agriculture, Ecosystems and Environment* 220: 164–174. DOI: 10.1016/j.agee.2016.01.005

Prudat B, Bloemertz L, Kuhn NJ. 2018. Local soil quality assessment of north-central Namibia: Integrating farmers' and technical knowledge. *Soil* 4: 47–62. DOI: 10.5194/soil-4-47-2018

Ramisch JJ. 2012. 'This Field Is Our Church': The social and agronomic challenges of knowledge generation in a participatory soil fertility management project. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World*. Routledge: Abingdon, Oxon, 146–174. DOI: 10.4324/9780203125434

Reed MS, Dougill AJ, Baker TR. 2008. Participatory indicator development: What can ecologists and local communities learn from each other? *Ecological Applications* 18: 1253–1269. DOI: 10.1890/07-0519.1

Richards M, Sapkota T, Stirling C, Thierfelder C, Verhulst N, Friedrich T, Kienzle J. 2014. *Conservation agriculture: Implementation guidance for policymakers and investors. Practice Brief: Climate-Smart Agriculture*. Food and Agriculture Organization of the United Nations

Richards P. 1985. *Indigenous agricultural revolution: ecology and food production in West Africa*. London (UK) Hutchinson

Rodenburg J, Büchi L, Haggar J. 2020. Adoption by adaptation: moving from Conservation Agriculture to conservation practices. *International Journal of Agricultural Sustainability* 1–19. DOI: 10.1080/14735903.2020.1785734

Rogers EM. 1983. *Diffusion of innovations*. The Free Press: Glencoe, UK. DOI: 10.4324/9781351163804-8

Rogers EM. 2003. *Diffusion of innovations*. The Free Press: New York, NY

Rosenstock TS, Lamanna C, Chesterman S, Bell P, Arslan A, Richards M, Rioux J, Akinleye AO, Champalle C, Cheng Z, Corner-Dolloff C, Dohn J, English W, Eyrich A-S, Girvetz EH, Kerr A, Lizarazo M, Madalinska A, Mcfatridge S, Morris KS, Namoi N, Poultouchidou A, Ravina M, Silva D, Rayess S, Ström H, Tully KL, Zhou W. 2016. The scientific basis of climate-smart agriculture A systematic review protocol CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). CCAFS Working Paper 138

Russell AW, Wickson F, Carew AL. 2008. Transdisciplinarity: Context, contradictions and capacity. *Futures* 40: 460–472. DOI: 10.1016/j.futures.2007.10.005

Savolainen R. 2017. Information sharing and knowledge sharing as communicative activities. *Information Research* **22**: 767

Schut M, Leeuwis C, Thiele G. 2020. Science of Scaling: Understanding and guiding the scaling of innovation for societal outcomes. *Agricultural Systems* 184. DOI: 10.1016/j.agsy.2020.102908

Scoones I. 2009. Livelihoods perspectives and rural development. *The Journal of Peasant Studies* 36: 171–196. DOI: 10.1080/03066150902820503

Simwaka PL, Tesfamariam EH, Ngwira AR, Chirwa PW. 2020. Carbon sequestration and selected hydraulic characteristics under conservation agriculture and traditional tillage practices in Malawi. *Soil Research*. DOI: 10.1071/SR20007

Steward PR, Dougill AJ, Thierfelder C, Pittelkow CM, Stringer LC, Kudzala M, Shackelford GE. 2018. The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments : A meta-regression of yields. *Agriculture, Ecosystems and Environment* 251: 194–202. DOI: 10.1016/j.agee.2017.09.019

Sumberg J. 2005. Constraints to the adoption of agricultural innovations: Is it time for a re-think? *Outlook on Agriculture* 34: 7–10. DOI: 10.5367/0000000053295141

Sumberg J. 2017. *Agronomy for development: The politics of knowledge in agricultural research.* Routledge: Abingdon, Oxon. DOI: 10.4324/9781315284057

Sumberg J, Irving R, Adams E, Thompson J. 2012a. Success-making and success stories: Agronomic research in the spotlight. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World.* Routledge: Abingdon, Oxon, 186–203. DOI: 10.4324/9780203125434

Sumberg J, Thompson J, Woodhouse P. 2012b. *Contested Agronomy: Agricultural research in a changing world*. Earthscan, Routledge: Abingdon, Oxon

Sumberg J, Thompson J, Woodhouse P. 2013. Why agronomy in the developing world has become contentious. *Agriculture and Human Values* 30: 71–83. DOI: 10.1007/s10460-012-9376-8

Swanepoel CM, Rötter RP, van der Laan M, Annandale JG, Beukes DJ, du Preez CC, Swanepoel LH, van der Merwe A, Hoffmann MP. 2018. The benefits of conservation agriculture on soil organic carbon and yield in southern Africa are site-specific. *Soil and Tillage Research* 183: 72–82. DOI: 10.1016/j.still.2018.05.016

Tesfaye K, Jaleta M, Jena P, Mutenje M. 2015. Identifying Potential Recommendation Domains for Conservation Agriculture in Ethiopia, Kenya, and Malawi. *Environmental Management* 55: 330–346. DOI: 10.1007/s00267-014-0386-8

The World Bank. 2016a. *Rural population (% of total population)* | Data from https://data.worldbank.org/indicator/SP.RUR.TOTL.ZS?locations=MW

The World Bank. 2016b. *Agricultural land (% of land area) - Malawi* | Data from https://data.worldbank.org/indicator/AG.LND.AGRI.ZS?locations=MW&view=chart

The World Bank. 2016c. *Poverty headcount ratio at national poverty lines (% of population) - Malawi* | Data from https://data.worldbank.org/indicator/SI.POV.NAHC?locations=MW&view=chart

The World Bank. 2016d. *Agricultural land (sq. km)* | Data from https://data.worldbank.org/indicator/AG.LND.AGRI.K2?locations=MW

The World Bank. 2019. *Population growth (annual %) - Malawi* | Data from https://data.worldbank.org/indicator/SP.POP.GROW?locations=MW&view=chart

Thierfelder C, Bunderson WT, Mupangwa W. 2015a. Evidence and Lessons Learned from Long-Term On-Farm Research on Conservation Agriculture Systems in Communities in Malawi and Zimbabwe. *Environments* 2: 317–337. DOI: 10.3390/environments2030317

Thierfelder C, Cheesman S, Rusinamhodzi L. 2012. A comparative analysis of conservation agriculture systems: Benefits and challenges of rotations and intercropping in Zimbabwe. *Field Crops Research* 137: 237–250. DOI: 10.1016/j.fcr.2012.08.017

Thierfelder C, Chisui JL, Gama M, Cheesman S, Jere ZD, Trent Bunderson W, Eash NS, Rusinamhodzi L. 2013. Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. *Field Crops Research* 142: 47–57. DOI: 10.1016/j.fcr.2012.11.010

Thierfelder C, Chivenge P, Mupangwa W, Rosenstock TS, Lamanna C, Eyre JX. 2017. How climate-smart is conservation agriculture (CA)? – its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Security* 9: 537–560. DOI: 10.1007/s12571-017-0665-3

Thierfelder C, Matemba-Mutasa R, Rusinamhodzi L. 2015b. Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. *Soil and Tillage Research* 146: 230–242. DOI: 10.1016/j.still.2014.10.015

Thierfelder C, Rusinamhodzi L, Ngwira AR, Mupangwa W, Nyagumbo I, Kassie GT, Cairns JE. 2015c. Conservation agriculture in Southern Africa: Advances in knowledge. *Renewable Agriculture and Food Systems* 30: 328–348. DOI: 10.1017/S1742170513000550

Thierfelder C, Wall PC. 2010. Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. *Journal of Crop Improvement* 24: 113–121. DOI: 10.1080/15427520903558484

Thompson J, Scoones I. 1994. Challenging the populist perspective: Rural people's knowledge, agricultural research, and extension practice. *Agriculture and Human Values* 11: 58–76. DOI: 10.1007/BF01530446

Tress G, Tress B, Fry G. 2005. Clarifying integrative research concepts in landscape ecology. *Landscape Ecology* 20: 479–493. DOI: 10.1007/s10980-004-3290-4

Trogrlić RŠ, Wright GB, Duncan MJ, van den Homberg MJC, Adeloye AJ, Mwale FD, Mwafulirwa J. 2019. Characterising local knowledge across the flood risk management cycle: A case study of Southern Malawi. *Sustainability* (Switzerland) 11. DOI: 10.3390/su11061681

Turreira-garcía AN, Lund JF, Domínguez P, Carrillo-anglés E, Brummer MC, Duenn P, Reyes-garcía V. 2018. What's in a name ? Unpacking "participatory" environmental monitoring. *Ecology and Society* 23. DOI: https://doi.org/10.5751/ES-10144-230224

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gérard B, Rufino MC, Teufel N, van Rooyen A, van Wijk MT. 2012. Conservation Agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research* 132: 175–184. DOI: 10.1016/j.fcr.2012.02.022

Vargas R, Omuto C. 2016. *Soil Loss Assessment in Malawi*.

Wall PC, Thierfelder CL, Nyagumbo I, Rusinamhodzi L, Mupangwa W. 2019. Comment on "De Roo et al. (2019). On-farm trials for development impact? the organization of research and the scaling of agricultural technologies." *Experimental Agriculture* 55: 185–194. DOI: 10.1017/S0014479718000492

Ward PS, Bell AR, Droppelmann K, Benton TG. 2018. Early adoption of conservation agriculture practices: Understanding partial compliance in programs with multiple adoption decisions. *Land Use Policy* 70: 27–37. DOI: 10.1016/j.landusepol.2017.10.001

Warren DM. 1991. *Using indigenous knowledge in agricultural development.* World Bank Discussion Papers 127

Whitfield S. 2015. *Adapting to Climate Uncertainty in African Agriculture: Narratives and Knowledge Politics.* Earthscan, Routledge: Abingdon, Oxon. DOI: 10.4324/9781315725680

Whitfield S, Dixon JL, Mulenga BP, Ngoma H. 2015. Conceptualising farming systems for agricultural development research: Cases from Eastern and Southern Africa. *Agricultural Systems* 133: 54–62. DOI: 10.1016/j.agsy.2014.09.005

Wigboldus S, Klerkx L, Leeuwis C, Schut M, Muilerman S, Jochemsen H. 2016. Systemic perspectives on scaling agricultural innovations. A review. *Agronomy for Sustainable Development* 36: 1–20. DOI: 10.1007/s13593-016-0380-z

Chapter 2

Bridging the disciplinary gap in Conservation Agriculture research, in Malawi. A review.

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Abstract

Conservation Agriculture has emerged as a popular form of climate smart agriculture aimed at enhancing climate change resilience for smallholder farmers across Africa. Despite positive biophysical results, adoption rates remain low. It has been acknowledged that improved understanding of farmer decision-making is needed due to the variation in socio-economic and agro-ecological contexts which drives the research agenda to answer the question ‘what forms of Conservation Agriculture work, where, and why?’. To fully understand this question, we need to approach the study of Conservation Agriculture within complex farming systems by collating and integrating different forms of knowledge. In this paper, we discuss (1) a comparison of disciplinary approaches to evaluating Conservation Agriculture in Malawi, (2) the identification of the knowledge gaps that persist at the intersection of these disciplines and (3) recommendations for alternative and interdisciplinary approaches in addressing these knowledge gaps. With a focus on published studies from Malawi, we show that the Conservation Agriculture literature represents two distinct approaches to addressing the question ‘what forms of Conservation Agriculture work, where, and why?’, namely agro-ecological and socio-economic and that neither of these approaches can address the full scope of this question, in particular its ‘why’ component. To overcome these challenges, there is a need for access to compatible, comprehensive data sets, methodological approaches including farmer participation and ethnography, through on-farm trial research as a middle ground between disciplinary approaches.

Keywords: Farming systems, Climate-smart agriculture, Southern Africa, No-tillage, Malawi

2.1 Introduction

Conservation Agriculture (CA) has been widely promoted across Africa as a way of improving the livelihoods of smallholder farmers, combining increased climate change resilience and soil carbon sequestration (Kassam *et al.*, 2009; Lipper *et al.*, 2014; Mupangwa *et al.*, 2017a). It is based on three practices: (1) minimum soil disturbance, (2) soil surface cover with crop residues and (3) crop rotation or diversification via intercropping (Figure 2.1) (FAO, 2015). Agronomic studies have shown that CA can improve soil water retention, decrease soil erosion and runoff, improve soil structure, quality, and biological activity allowing earlier crop planting (FAO, 2008; Thierfelder *et al.*, 2015c, 2017; Thierfelder & Wall, 2009). Further literature has shown its potential to enhance soil fertility, heat and dry spell resilience, and crop productivity (Steward *et al.*, 2018; Thierfelder *et al.*, 2015c; Thierfelder & Wall, 2010a). Extrapolating from this evidence of soil and yield improvements, narratives of socio-economic benefits, such as labour saving, womens' empowerment, food security and improved rural livelihoods, have become mainstreamed into the promotion of CA (Whitfield *et al.*, 2015b). There is also a recognition that these benefits do not play out for all people in all places and that there is a need to adapt CA practices to local agro-ecological and socio-economic contexts (Andersson & Giller, 2012). Adoption rates have remained low in southern Africa (Andersson & Giller, 2012; Ward *et al.*, 2018), unlike in Brazil and Argentina where adoption rates have reached > 70% (Kassam *et al.*, 2019).

Figure 2.1 Left: Malawian conventional ridge and furrow treatment without residues. Right: conservation agriculture treatment with residue cover, minimum tillage and crop rotation or intercropping. The photos of the conventional and conservation agriculture treatment were taken on CIMMYT on-farm trials in Malawi

Previous discussions on farmers' adoption of new agricultural innovations have shown that farmers' motivations for adoption are diverse (Biggs, 1989; Fujisaka, 1994). Low adoption rates and recognition that there are multiple ways in which agro-ecological and socio-economic context interacts with CA land management practices, continues to drive research efforts to understand what forms of CA work, where, for whom and why? The body of literature that can be considered as contributing to these questions is growing and diverse, covering both agronomic aspects of soil-plant-water interactions, and socio-economic aspects of decision-making, labour and resource constraints.

Within this body of literature, the way in which the problem of low adoption is framed may be contributing to the difficulty of understanding the reasons for it. The notions of adoption (and non-adoption or dis-adoption) inadequately reflect the complex ways in which farmers interact with, trial, experiment with and adapt agricultural technologies and techniques (Brown *et al.*, 2017, 2018a; Giller *et al.*, 2009; Pannell *et al.*, 2014). Within academic CA literature, there are relatively few studies that aim to understand CA-related practices within the broader knowledge and decision-making context of farming systems. These limitations are not confined to issues of adoption, but also relate to understanding the interactions between farming practices, the local agro-ecological conditions and more broadly the knowledge and decision-making processes of farmers.

In this paper, we systematically review existing literature focused on Malawi on the question ‘what forms of CA work, where, for whom, and why?’. We map out the approaches that are commonly taken to address this question and the contributions that have been made across a broad and growing body of literature. We consider the potential compatibilities between different approaches and what can be learnt through a cross-disciplinary reading of this evidence base. We also consider the limitations of existing evidence, by revealing some of the incompatibilities between different disciplinary approaches, asking ‘why do knowledge gaps persist?’, and what the alternative ways of interpreting and understanding the ‘CA paradox’ of low adoption are.

In Malawi, the agricultural sector provides work for 80% of the working population and contributes approximately 35% of the GDP (Ngwira *et al.*, 2012a; Tesfaye *et al.*, 2015). Malawi is one of the southern African countries where CA has been argued to be favourable because of its low ruminant livestock density, high rural population density and challenges with soil degradation (Asfaw *et al.*, 2018; Ngwira *et al.*, 2012a, 2012c; The World Bank, 2016; Valbuena *et al.*, 2012). However, a number of recent studies (Chinseu *et al.*, 2019; Dougill *et al.*, 2017) have highlighted institutional and socio-cultural reasons for the low levels of CA adoption. This study investigates the approaches adopted by CA literature to understand: ‘what forms of CA work, where, for whom, and why?’. The aims of this study are therefore to (1) compare disciplinary approaches to evaluating CA in Malawi, (2) identify the knowledge gaps that persist at the intersection of these disciplines and (3) make recommendations for alternative and interdisciplinary approaches in addressing these knowledge gaps.

2.2 Theoretical framework

The dynamic interactions between social histories, rural livelihoods and economies, climatic and agro-ecological conditions, resources and technological change, decision making, including trade-offs, all underpin farming systems research (FSR). FSR has become popular since the 1970s as a way to address the dynamic conditions of farming and the involved decision-making (Whitfield *et al.*, 2015a). Since the start of FSR as a discipline, its application and methods have diversified from addressing adoption constraints and farmer participation to examining farming processes, functionality and infrastructure (Collinson, 2000; Whitfield *et al.*, 2015a). However, agricultural research continues to be largely approached through discipline specific approaches (e.g., social science, agronomy, economics, climate impacts) that focus on component parts of the system. These disciplines are associated with specific norms, methodological approaches and ontologies.

Individual disciplinary approaches can contribute to an understanding of the what, where and for whom questions of CA. For example, in analysing agronomic field trial data from global CA studies, Steward et al. (2018) showed that CA's performance improves, relative to conventional practices, with drought and heat severity and with low soil clay contents. Thierfelder et al. (2017) found that in agronomic trials across southern Africa that CA maintains higher soil moisture contents during dry spells but can lead to yield reductions during heavy rainfall. Additionally, they suggest that CA increases profitability, although only after 2–5 years, depending on farmer skills and management precision (Thierfelder *et al.*, 2017). Other scholars, such as Whitfield et al. (2015b), apply a critical reflection on the evidence base for CA narratives, to enable the mapping of the 'what' and 'for whom' evidence. From other social science papers, such as Fisher et al. (2018) and Holden et al. (2018), we have learnt about information and technology distribution through farmer-to-farmer extension and lead farmers. Therefore, individual disciplinary approaches have contributed to specific parts of the what, where and for whom questions of CA.

As Whitfield et al. (2015b) show in the context of Zambia, the creation of the evidence base for the CA narratives started in controlled environments (managed by research institutes) focusing on agronomic benefits (e.g., Thierfelder & Wall, 2009, 2010a, 2010b; Vogel, 1994). On the other hand, the adoption and (socio-)economic studies mainly focus on inputs, labour, production and profitability evaluation, but there has rarely been interactions across these isolated disciplinary studies (Grabowski *et al.*, 2016; Ngwira *et al.*, 2012a, 2012b). Andersson and D'Souza (2014) suggest that CA's narrative in southern Africa has been shaped by the development community in socio-economic and institutional contexts.

Despite efforts by various disciplines to increase our knowledge on the aspects of what, where and for whom CA is suitable, the discussed CA paradox of low adoption despite positive biophysical results persists. There are certainly more knowledge gaps in the 'what', 'where' and 'for whom' aspects of this broader question still to be filled, but we hypothesise that it is particularly in the 'why' component of the question — in understanding why CA is favourable to, and practiced by certain people in certain contexts, and not by others — where the most fundamental gaps in knowledge persist.

Different theories about why CA does or does not work tend to emerge from different disciplines, themselves reflecting different sets of assumptions, methodological approaches and problem framings (Leach *et al.*, 2010; Sumberg *et al.*, 2012). These theories, whether about labour availability, soil properties, institutional environments, climate, innovation dynamics or any number of other aspects, are rarely wholly adequate on their own. However, collating across this broad body of CA research is also difficult because of the ontological and methodological differences that characterise different research approaches. Integrating across different knowledges and disciplines has three main challenges according to Black (1998, 2002): the foundation and infrastructure for communication between disciplines, the language and terminology collating across disciplines and their understanding and the different perceptions on the discussed issue. As a direct response to these challenges, in this paper, we map out the approaches to research on CA in Malawi, to explore whether there is a disciplinary and conceptual gap and to characterise this in terms of language and issue perception, as a basis for reflecting on how the integration and communication across the CA research landscape might be achieved.

2.3 Methodology

To evaluate the literature on CA in Malawi, we conducted a realist systematic literature review (Antwi-Agyei *et al.*, 2015; Biesbroek *et al.*, 2013; Thompson *et al.*, 2010). This approach focuses on depth and qualitative analysis as opposed to quantity as is the case with a systematic approach. Literature searches were conducted in the publications databases Scopus and Web of Science (WoS). The search terms were selected to cover the diversity of terminology used to describe CA, constraints, farmers and geographical area (Table 2.1). Various search terms were tested to ensure capturing a wide variety of literature for the next selection phase. All collected literature (WoS 94 papers, Scopus 56) from the search was reviewed based on titles, abstracts and full texts and a selection was made based on the selection criteria (Table 2.2). After selection, 40 articles were deemed relevant.

The articles were reviewed based on four key points, identified to highlight the component parts of the broader questions, namely, (1) what CA is (i.e. how CA practice is defined and described), (2) what it means to work (i.e. how CA success is defined and measured), (3) where and for whom (i.e. the contextual and determinant factors of success that are considered) and (4) why (i.e. the explanatory mechanisms for success in particular contexts that are presented). The first framing condition focuses on the variety of used CA definitions, followed by framing condition 2 on what is considered as CA being successful (i.e. success metrics). Framing condition 3 examines the conditions of the CA studies and the provided information on these conditions. Lastly, framing condition 4 considers if studies present the drivers and explanations behind CA's performance and suitability. Following the grounded theory approach (Glaser & Strauss, 1967), information according to the four key points and framing conditions was collected for all papers and used for qualitative coding. After all the codes in response to the four key points were collected, each paper was assigned binary numbers for each of these codes (1 = yes and 0 = no). The binary values assigned to the identified codes enabled us to apply a cluster analysis and create a dendrogram in SPSS Statistics 23.0.0.2 (IBM Corp, 2015). The cluster analysis method selected is the hierarchical cluster analysis according to Ward's method, which is also used in standard statistical analysis such as ANOVA (Ward, 1963). The distance measure selected for the binary data is the Euclidean distance (i.e. direct geometric distance).

Table 2.1 Search string for the literature search in SCOPUS and Web of Science on 2/03/2018, a second search and literature update was performed on 29/08/2019

Conservation Agriculture OR Sustainable Intensification OR Climate Smart Agriculture OR no*till* AND soil OR (adopt* OR implement* OR practice OR constrain OR challenge OR limit*) AND Farmer* OR Small*holders AND Malawi

Table 2.2 Selection criteria for this literature review.

Included	**Excluded**
English only	Global or African studies excluding Malawi
Available in Web of Science and Scopus	Climate Smart Agriculture in general
Conservation agriculture	Modelling only papers focusing on simulations
Peer-reviewed articles, reviews, book chapter	Conservation Agriculture not specifically mentioned

2.4 Framing conditions 'what forms of CA work, where, for whom and why?'

2.4.1 Framing condition 1: what is CA?

The framing question 'What is CA?' focuses on the definition of CA including the practices that are evaluated in the studies. The time aspect in the definition (e.g., how long before we call it CA?) is in most cases not part of the definition, but some studies consider the effect of time on the results (framing condition 3). In some cases, CA's three main practices are used or the practices adopted by farmers defines the working definition (n=19). There is a group of literature, which provides detailed technical prescriptions (n=20) or information on additional agronomic practices and guidelines (n=27) that are needed for successful functioning of CA. These practices include fertilizer, herbicide, organic manure (Fisher *et al.*, 2018; Mupangwa *et al.*, 2017b), agroforestry tree species (Andersson & D'Souza, 2014) and seeding patterns including spacing and planting methods (Bunderson *et al.*, 2017; Mupangwa *et al.*, 2017b; Mutenje *et al.*, 2019; Ngwira *et al.*, 2012c, 2013; Thierfelder *et al.*, 2013b, 2015c, 2016a), ripping (Mutenje *et al.*, 2019; Thierfelder *et al.*, 2015c) and basin planting (Mutenje *et al.*, 2019; Thierfelder *et al.*, 2015c). In the paper by Thierfelder et al. (2016a), CA is defined as no-till with residue cover and dibble stick planted maize only in one treatment and maize (*Zea mays L.)* - cowpea (*Vigna unguiculata L.*) intercropping in the other - the later following the stringent definition of FAO with all three principles covered while the former being an 'incomplete CA-based system'. Additionally, maize row spacing (75 cm and 25 cm between stations), seed quantity (1 seed per planting station) and the fertilizer rates (69 kg ha^{-1} N:21 kg ha^{-1} P_2O_5:4 kg ha^{-1} S) are also provided. Other papers, such as Mloza-Banda et al. (2016), include information on the chemical weed control.

Some of the papers question CA definitions and are critical about them (n=4). In some cases, farmers self-define what they consider CA practices or select the individual practices they implemented (e.g., only no till and residues, or only residue retention) (n=4). In four cases, only two CA practices (no-till and residue retention) within the CA definition were tested (Khataza *et al.*, 2018; Ngwira *et al.*, 2012b, 2014a; Thierfelder *et al.*, 2013c), and in some cases, CA adoption and preference were discussed per practice (Bell *et al.*, 2018; Chinseu *et al.*, 2019; Ward *et al.*, 2016, 2018). The study by Khataza et al. (2018), for example, only focused on minimum tillage and residue retention because these were new practices in the study area. Lack of precision in the definition of CA and no-till systems have been previously highlighted as lack of clarity about what the research or promotion is all about and what the results actually mean if incomplete CA systems are described, or where CA adoption is only short-lived (Chinseu *et al.*, 2019).

The precision of treatment descriptions is often due to research or promotion taking place in controlled field trials, demonstrations or research stations. This provides the possibility to implement the needed treatment design control to enable comparison (Nyagumbo *et al.*, 2016; Thierfelder *et al.*, 2013a, 2015b, 2016a). These studies often represent context-specific variations of CA. This is reflected in the trial design variation in conventional practice, fertilizer recommendation, seeding practices (n=13) or legumes or plant varieties (n=13) to make it suitable for local adaptation and uptake.

For example, divisions for geographical areas can be found in Thierfelder et al. (2015b), the CA Malawi treatment is described as no-till with 2.5-3.0 t ha^{-1} residue retention rate, dibble stick planting, intercropping in one treatment with pigeon pea (*Cajanus cajan L.*) (southern) or cowpea (*Vigna unguiculata L.)* (central), 75 cm maize row spacing and 25 cm station spacing, whereas for Mozambique, basin planting with specific dimensions, similar residue retention rates and no till was used in one treatment and dibble stick or jab planter direct seeding in the other treatment. The used fertilizer rate of 58 kg ha^{-1} N:24 kg ha^{-1} $P_2 0_5$:10 kg ha^{-1} $K_2 0$ was different from the one used in Malawi (69 kg ha^{-1} N:21 kg ha^{-1} $P_2 0_5$:4 kg ha^{-1} S). Glyphosate for weed control was used on clay soil types but manual weeding with hoes on sandy soils due to perceived environmental hazards on the very sandy soils. The rotation in similar trials in Zimbabwe and Zambia was done with cowpea (or soybeans in Northern Zimbabwe). Additionally, fertilizer rates were higher than Zimbabwe because of local blending and recommendation. The definition of the CA practices is therefore not subject to the farmers themselves but defined by researchers who are able to share the recorded details of these practices. The CA definition as stated by the FAO is based on the three core principles and allows for adaptation to the local system for inputs. Reviewing the literature, however, we find a difference in precision of the CA description and little information on how local input or plant variety adaptations impact CA's performance. This challenges comparing CA's performance between studies and eventually answering 'what forms of CA work, where, for whom and why?'

2.4.2 Framing condition 2: what does it mean for CA to work?

The most popular measures of success in most of the studies was increased yield or greater yield stability (n=18). This metric of success is used both in biophysical and economic assessment and in relation to soil health indicators. In TerAvest et al. (2015), yield is measured besides infiltration, soil moisture, pH and soil organic carbon, whereas Ngwira et al. (2012c) measures harvest, besides soil health indicators and profitability. Another popular measure of CA's success is gross margins, income and profitability change of farmers (n=11). In some cases, these costs have been used as measurement of success in themselves, with value placed on metrics such as reduced labour and input costs, as well as ease of weeding (Bunderson *et al.*, 2017; Johansen *et al.*, 2012). In Ngwira et al. (2012a), an economic analysis in the form of partial budget analysis was used based on labour data in time per activity, prices of inputs and variable costs determined by the involved extension officer. The profit was determined with the use of average farm gate prices for maize and pigeon pea. In Bunderson et al. (2017), income from harvest, costs and gross margins are calculated for CA and conventional tillage.

Other forms of quantitative bio-physical measures of CA efficacy used include various soil chemistry, physics or biology indicators such as soil structure, particle size, bulk density, aggregate stability (n=9), carbon (n=10), water infiltration, soil moisture, water tension or logging (n=10), soil fauna (n=5), pH (n=4), N (n=3), P (n=2), erosion (n=2), soil temperature (n=1) or other chemical indicators such as K, Ca, Zn (n = 1). Other measures of success include weed (n=2) and pest suppression (n=2). Even when considering specific metrics, there can be different ways of interpreting and understanding what it means for CA to 'work'. In case of the soil data, it often used to assess 'improvement' in soil health or soil quality. Soil quality is considered as looking at a combination of inherent and dynamic properties whereas soil health mainly focuses only on dynamics attributes (Bünemann *et al.*, 2018). These concepts cover physical, chemical and biological indicators active on different timescales, or adapted to the soil function including the assigned indicator weights. Mloza-Banda et al. (2014) and Mloza-Banda et al. (2016) have used a soil structural stability index, which considers soil physical factors. However, none of the other studies has used indices to quantify or make statements about soil health or quality but presented different properties or attributes in isolation without breaking them down to a single indicator.

The extent of CA adoption is also popular as a success indicator (n=17) and can be used in numbers (e.g., how many adopters) or as practices (e.g., what practices are adopted) therefore being quantitative or qualitative. Although adoption is not a direct indicator of the biophysical or socio-economic efficacy of CA, it is sometimes assumed to be a proxy, and thus used as measure of success. In the case of adoption numbers, a majority of the research worked with a quantitative binary system suggesting adoption or non-adoption. Andersson and D'Souza (2014) in particular reflect on the methods that have been used to assess adoption, including the role of variation in definitions, input subsidies and project promotions. Recently, it has been suggested that a non-binary system accounting for the extent of adoption is more suitable because the definition of CA is variable across regions and full adoption is a rarity (Brown *et al.*, 2017). This is supported by studies addressing CA (dis)adoption as preferences and adoption of individual practices change through time (Bell *et al.*, 2018; Chinseu *et al.*, 2019; Ward *et al.*, 2016).

Some studies use qualitative only measures of success such as CA adaptation to local conditions (n=4). For example, Kaluzi et al. (2017) conducted interviews and a survey with farmers to assess their decision making and CA adaptation. They found that 58% did not adapt CA to their context because they followed the exact guidelines of extension services. Additionally, they pointed out that > 50% of the farmer proposed solutions were not documented by extension officers, as they were not considered proven (Kaluzi *et al.*, 2017). In our review, there were ten papers, of which nine were from 2017 to 2019, that explicitly used farmers' attitude, motivation and transfer of knowledge as a measure of success. Only in four cases are the dissemination of the innovation, familiarity with CA, demonstrations and farmers' recommendation used as measures of success (Brown *et al.*, 2018b; Fisher *et al.*, 2018; Holden *et al.*, 2018; Khataza *et al.*, 2018). In Fisher et al. (2018), CA adoption was analysed as a two-step process including first familiarity with the technology in relation to adoption, showing that lead farmers' familiarity with and adoption of CA technologies increase likeliness of followers' familiarity. In four studies, the information from different stakeholders was discussed, thereby examining institutional and policy advocacy. In the case of Brown et al. (2018c), the perspective from local researchers was examined, and in Brown et al. (2018b), the perspective of agricultural extension providers. Furthermore, the study based on a national multi-stakeholder workshop by Dougill et al. (2017) shed light on the perspective of 18 key institutions including government, CGIAR, NGOs and the National Smallholder Farmer Association of Malawi (NASFAM). Reviewing the measures of success, there is a variety of agro-ecological and socio-economic indicators of success, which are rarely integrated or combined. In particular, the quantitative methods in the agro-ecological or economic disciplines are popular measures for assessing if CA works.

2.4.3 Framing condition 3: where and for whom?

Across the reviewed studies, a variety of variables are considered in order to determine the conditions under which CA works. The most common conditions tested are spatial differences in agro-ecological variables, including climate conditions (n=26) and soil type (n=23). Soil type and climatic conditions, in particular rainfall, play a crucial role in attaining CA's benefits with studies finding that CA's benefits are especially apparent in drier environments and low fertility soils (Ngwira *et al.*, 2012c; Nyagumbo *et al.*, 2016; Thierfelder *et al.*, 2013b, 2015c, 2015a). In the study by Cheesman et al. (2016), soil carbon and bulk density were measured in two regions in Malawi (7 communities), 3 provinces in Mozambique (10 communities), 1 province (1 community) in Zambia and 3 provinces (5 communities) in Zimbabwe. Only few articles mentioned livestock density or ownership, and its relation to mulching practices, as a condition tested for in relation to CA performance (n=5). In Ngwira et al. (2014b), Tropical Livestock Unit is selected as an explanatory variable to understand if a higher livestock density will lead to more residue competition and therefore lower adoption likelihood.

Conditions in communities or real-world farming systems (as opposed to controlled trial sites) are less controllable and therefore the line between the tested conditions and the contextual conditions can be vague. Demographic information (n=11) about the contexts that is provided in some studies includes, gender (n=9), education (n=9), household size (n=8), marriage status (n=6), production (n=5), duration of CA practice (n=3), resource access and poverty (n=8), labour (n=8), land size (n=7), age (n=7), CA practices adoption (n=7), CA or off farm income (n=3) and input subsidy (n=4). The study by Kaluzi et al. (2017), for example, presents demographic data for the various communities in which the surveys have taken place but does not explicitly use them as explanatory variables. On the other hand, the demographic data in the paper by Ngwira et al. (2014b) are used as explanatory variables (e.g., education, family size, gender, age, labour, input subsidy and farmer group membership) for their analysis of CA adoption, using statistical inferences. Other commonly described conditions which make the research context unique are the introduction, promotion and history of CA and the institutional setting and NGO involvement (n=17). Furthermore, papers focusing on farmer attitudes report on the farmer exposure, knowledge and motivation as conditions (n=16). Some recorded significant factors affecting CA adoption rates are gender (Holden *et al.*, 2018; Ward *et al.*, 2018), hired labour (Ngwira *et al.*, 2014b), maximum education (Ward *et al.*, 2018), peer compliance (Ward *et al.*, 2018), area location (Ngwira *et al.*, 2014b; Ward *et al.*, 2018), age (Holden *et al.*, 2018; Makate *et al.*, 2019), number of incentives or trainings received (Holden *et al.*, 2018), support from farmer organization or non-faith based NGOs (Ward *et al.*, 2016), land size of cultivated land (Makate *et al.*, 2019; Ngwira *et al.*, 2014b; Ward *et al.*, 2016), household contact to extension (Makate *et al.*, 2019), farmer group membership (Ngwira *et al.*, 2014b), current practice of one of the three CA practices (Ward *et al.*, 2016) and crop loss due to rainfall or insects (Ward *et al.*, 2016).

Another discussed factor for CA's assessment is the role of social networks and social groups (n = 12), including farmer schools, farmer-to-farmer networks or NGO memberships. Two studies in particular tested the role of social networks and its impact on CA adoption. The study by Fisher et al. (2018) discusses the role lead farmers (and the farmer to farmer extension) play in the adoption of and familiarity with CA. They showed that lead farmer adoption and familiarity affects CA distribution, and their motivation enhances the CA implementation by their followers. The paper by Holden et al. (2018) also focused on the role lead farmers played using a promoter-adopter approach. They concentrate on the CA practices recommended to followers by the lead farmers, of which 45% would recommend minimum tillage, 27% mulching and 49% crop rotation (Holden *et al.*, 2018).

Time also plays an important role in CA research as a condition due to benefits in the form of yield only being recorded after a couple of years (n=14). Additionally, time is also tested as a condition based on the assumption that the longer farmers are exposed to CA to more likely they gain knowledge, or adopt CA (Cheesman *et al.*, 2017). Reading across the literature, the conditions tested under which CA works and the approach to testing these conditions varies. Whereas in the agro-ecological studies, these tested conditions are more controlled (e.g., soil type, climate, varieties), the line between the tested and contextual conditions in the socio-economic studies is less distinctive.

2.4.4 Clustered framing conditions

The identified codes were divided according to the themes that were found when analysing the papers for the framing conditions (Table 2.3). These codes were assigned binary values (1 = present, 0 = absent) to enable a cluster analysis.

Table 2.3 Codes used for cluster analysis, based on literature provided answers to the three framing conditions. N shows how many studies were identified with a 'yes' response to the code.

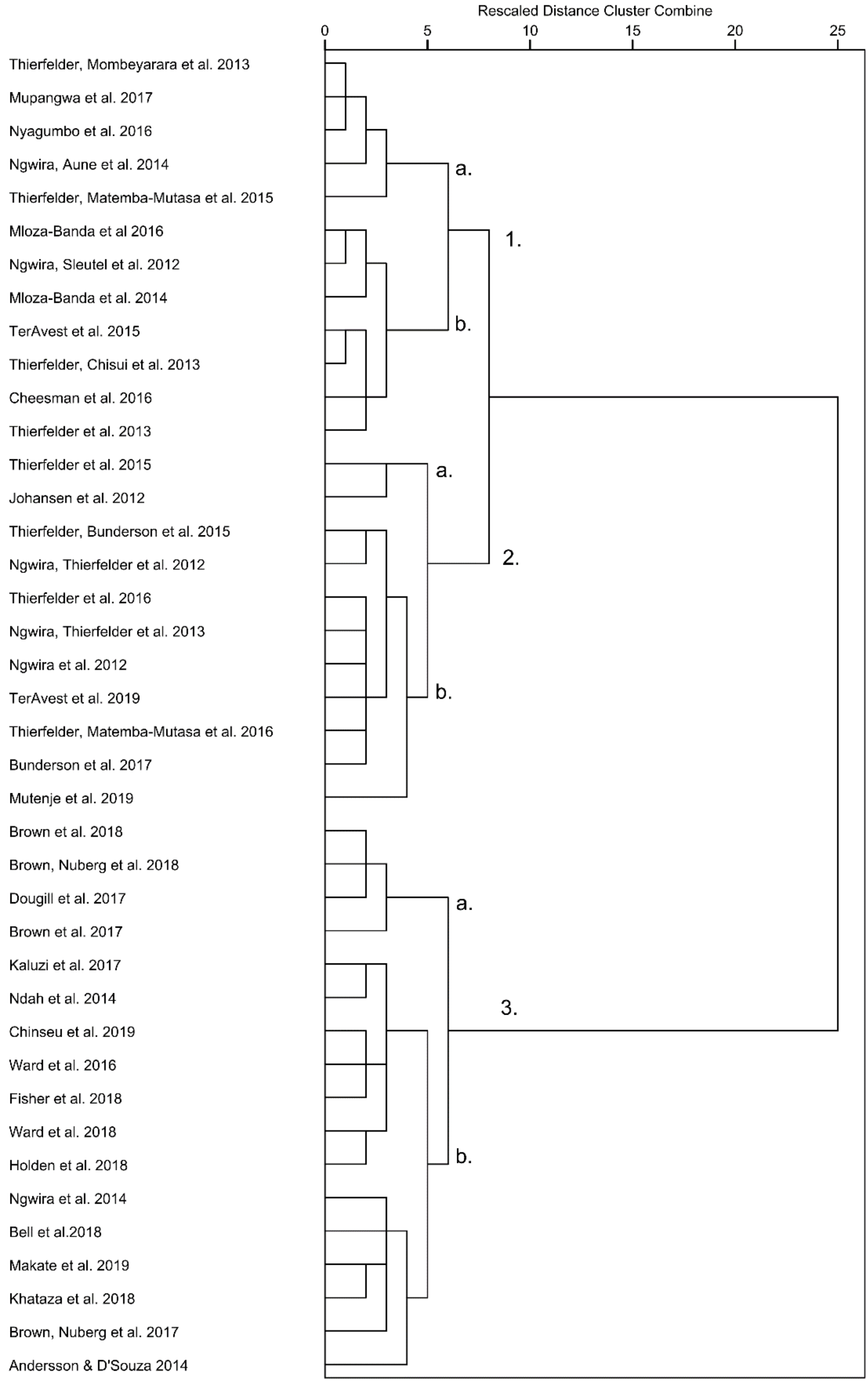
Framing Condition 1 : What is CA?	**n**	**Framing Condition 2: What does it mean for CA to work?**	**n**	**Framing Condition 3: Where and for Whom?**	**n**
CA self-defined	4	Yield	18	Climate conditions	27
Critical evaluation of CA definition	4	Income, labour, input costs and profit	11	Soil type	24
Three basic CA principles but not pre-scripted	19	Soil Chemistry	11	Livestock density or ownership	5
CA Technical prescription	20	Soil Physics	12	Household Demographics	11
Additional practices and guidelines	27	Soil Biology	5	Resources	22
		Weed and Pests	4	Labour	17
		Adoption	17	Land size	7
		Farmer attitude & transfer of knowledge	10	Promotion History & institutional involvement	17
		CA Adaptation	4	Farmer exposure knowledge and motivation	16
		Institutional and policy advocacy	4	Social networks and groups	12
				Cropping system and plant varieties	21

A distinction between clusters of literature can be observed based on the tested conditions, success metrics and definition as shown in the dendrogram (Figure 2.2). The dendrogram shows two main clusters and further subdivision intro three sub-clusters. When considering the literature in each of the clusters, it shows that the first cluster can be characterised as having a predominantly agro-ecological focus. The sub-division into two clusters (numbers 1 and 2) is caused by the use of econometric metrics of success (e.g., input prices, yield income, labour hours per activity) in the papers in cluster 2. These papers therefore use a technical definition, trial conditions and agro-ecological measurements but additionally use profits as a measure of success and considered conditions. The two sub-clusters (a and b) within cluster 1 are caused by a difference in success measurements. Sub-cluster a does not include soil measurements, whereas sub-cluster b does. The sub-clustering within cluster 2 can be explained by the type of paper. Sub-cluster a includes two review papers and discusses more factors for framing condition 2 (what does it mean for CA to work?) than the papers in sub-cluster b. In cluster 2, there is a single branch to one paper that focuses on econometrics but also has farmers' attitude and perspectives included, thereby integrating trial and survey data (Mutenje *et al.*, 2019). Overall, cluster 2 approaches the 'what' part of the question with detailed technical definitions that are often pre-scripted due to controlled trials. Its success is often measured in quantitative results on agro-ecological parameters (e.g., soil, yield) or including quantitative econometrics. The 'where and whom' part of the question are most frequently addressed in terms of different climate and environmental contexts, such as soil type, cropping system, and rainfall.

Cluster 3 consists out of the social science literature using basic three CA practices only without further prescriptions. This cluster focuses on transfer of knowledge, institutional context or household demographics as success metrics or research conditions. The clustering within this group is due to the inclusion of an institutional focus in the sub-cluster a papers as opposed to the papers in sub-cluster b that do not include an explicit institutional focus. The approach to the 'what' part of the question is therefore not pre-scripted but based on the three concepts, self-defined by farmers or critically discussed. The success metrics in this group are both quantitative in terms of adoption numbers and economic demographics, but also qualitative in terms of farmers attitude and transfer of knowledge. The 'where and for whom' conditions in this cluster are diverse due to the acknowledgement of diverse farming community contexts. The characteristics of these sub-clusters therefore show that they have a distinct approach to the 'what, where, for whom' questions.

The identified agro-ecological and socio-economic clusters reflect epistemological differences. Cluster 2 may intersect the disciplines of agro-ecology and econometrics, but it is based on agro-ecological definitions and conditions and is oriented towards realism and objectivism. It uses economic data collected in researcher-controlled environments through surveys or interviews as measure of success. On the other hand, socio-economic cluster 3 is increasingly embedded in subjectivism. However, most studies in cluster 3 still utilise researcher controlled interviews, focus groups and surveys for data collection. Therefore, the level of participatory methods or ethnography is higher in the socio-economic cluster, but only two papers self-acclaim utilizing participatory questions or methods (Dougill *et al.*, 2017; Ndah *et al.*, 2014). In one case, the context in which the research is conducted, which also serves the purpose of CA dissemination, is acclaimed as participatory (Bunderson *et al.*, 2017). Additionally, there was only one study, based in cluster 3, using an ethnographic approach (Bell *et al.*, 2018).

Figure 2.2 Dendrogram showing clusters based on the reviewed literature hierarchical cluster analysis in SPSS 23.0.0.2. Cluster 1 shows agro-ecological studies, cluster 2 shows agro-ecological and econometrics studies and cluster 3 socio-economic studies.



A majority of the agro-ecological papers are based on data from CIMMYT field trials, both on-farm and from research stations. The reviewed literature in this cluster is predominantly published in agricultural and soil journals. A review of the journals cited by the included papers shows that the studies cite mostly crop, soil and agronomy journals (e.g., Soil & Tillage Research, Field Crops Research, Soil Science Society of America Journal). In the socio-economic papers, there is a larger diversity in authors and research groups. A majority of the papers in this cluster are published in the last 2 years, whereas in the agro-ecological cluster, the studies have a longer age range, with only three papers from the last 2 years. The journals for publication of the socio-economic literature are land management and sustainability focused.

The cited literature in these studies is widely drawn from economics, management, sustainability and development journals (e.g., American Journal of Agricultural Economics, Agricultural Economics, Food Policy, The Journal of Agricultural Education and Extension). Additionally, the cited literature in this cluster shows a higher diversity in cited journals compared to the agro-ecological papers. Therefore, there are articles (Andersson & D'Souza, 2014; Giller *et al.*, 2009; Kassam *et al.*, 2009; Thierfelder *et al.*, 2013c, 2015c) cited across the literature but the review of the authors, journals and cited journals shows that there is a distinction between the clustered discipline groups.

2.4.5 Framing condition 4: why?

Our analysis of the different clusters of papers shows that within the agro-ecological cluster, it is more common to use a hypothesis, which is tested on controlled research stations and trials. This does not always result in understanding the drivers behind these measurements (thus answering the 'why part' of the research question in this study). For example, the papers using soil health indicators typically use process-based arguments to justify chosen indicators. Statistical models are applied to show a relation between contextual factors and yield data. These include the treatment (CA vs non-CA), CA concepts, site or season (n=14), or specifically soil type and rainfall (n=1). More commonly, statistics are used to check the soil indicator results per treatment, such as C or N indicators (n=8), water dynamics (n=8) or soil chemical and physical attributes (n=6). Only in a few studies were soil health indicators used in statistical tests to examine relation to yield or interaction (n=4); therefore, a significant number of soil physical or soil chemistry results are reported without insight on the pathways leading up to the observed yield result or water dynamics.

Within the socio-economic cluster, there are different approaches to handling the why question, which can be qualitative or quantitative. In cases where data is collected in the form of demographic results for context description, statistics were used to assess the interaction and most influential factors based on the demographic results such as household size, gender, site or education. In other papers, qualitative responses were collected and shown in frequency numbers or used to show the diversity of answers and possible drivers of decision-making (Kaluzi *et al.*, 2017). The qualitative approach and demographic statistical models especially focus on the ‘why’ part of the question including the drivers of decision-making. This cluster therefore has a stronger focus on the why part of the question which will be accompanied by contexts addressing the ‘what, where and for whom’. However, the less controllable research conditions and complex farming community contexts make these drivers difficult to extrapolate or generalise.

2.5 Characterising and comparing disciplinary approaches to evaluating CA in Malawi

The systematic literature review and analysis presented here reveal a clear distinction in approaches to CA research. Our analysis demonstrated that there is a sub-clustering in the agronomic studies (cluster 1 and 2), where some studies include an economic analysis with the biophysical metrics. These studies do still apply a technical CA definition, use quantitative metrics and often controlled conditions. Conversely, there are socio-economic studies that have looser (sometimes farmer-defined) definitions of what CA is, have socio-economic (increasingly qualitative) metrics of success and do not have well-controlled variables to test. The distinct approaches lead to only partial answers to the key question of what forms of CA work, where, for whom and why? and create knowledge gaps that exist in the gap between the approaches.

The illustrated clustering represents two distinct ontologies and epistemologies. Natural science is oriented towards realism (ontology) and objectivism (epistemology). This means that it strives for objective empirical observation with the use of scientific methods, assuming one independent objective reality (e.g., measured biophysical results on CA trials) (Crotty, 1998; Moon & Blackman, 2014). On the other hand, the socio-economic literature can also be embedded in relativism (ontology), constructionism or subjectivism (epistemology) (Crotty, 1998; Moon & Blackman, 2014). These studies therefore focus on the interaction between object (e.g., CA) and subject (e.g., farmers), considering the subject’s context such as history, culture and morality. These differences in approaches to agronomic research questions and the need to integrate these forms of knowledge can also be found in other agronomical debates such as System of Rice Intensification (SRI) (Sumberg *et al.*, 2012). These distinct approaches are products of embedded methodologies, framings or principles; therefore, they are self-reinforcing and challenging to bridge (Whitfield, 2015). When the goal is to cross these disciplinary divides, it means not only methods will need to be integrated but also the associated ontologies.

2.6 The knowledge gaps that persist at the intersection of these disciplines

In controlled studies, it is difficult to account for the multiple ways in which farmers practice and adapt CA, the multiple metrics of success that they might apply in evaluating it, or the diversity of socio-economic and agro-environmental conditions that might affect this 'success'. The precision with which the agricultural practices on research stations (or researcher managed on-farm trials) are carried out create 'high internal validity' and enables an exact and robust evaluation of the innovation, as required in (biophysical) agronomic research (Stevenson *et al.*, 2014). At the same time, this limits the research by not accounting for socio-economic conditions and farmers' decision making (Giller *et al.*, 2011; Stevenson *et al.*, 2014). The feasibility and suitability of these agricultural practices for smallholder farmers are not reflected in these studies. The socio-economic studies trying to fill this knowledge gap are more at risk of doubtful internal validity because of challenges such as farmer heterogeneity and participant selection bias (Stevenson *et al.*, 2014). In socio-economic studies, there is a lack of systematic, replicable documentation of agronomic conditions, practices and success metrics. It is therefore difficult to create an understanding of what works where and why, from these contextualised studies.

The lack of compatible data and metrics across these different types of studies means that it is difficult to integrate across these clusters to build a more complete picture of **what forms of CA work, where, for whom, and why?**, in particular the why part of this question. Detailed biophysical data is rarely collected as part of community-based research, nor are socio-economic metrics of success as part of controlled field trial experiments. It is uncommon to use controlled experimentation to systematically test the insights that come from community research. Additionally, the biophysical conditions on farms are often not commonly compared with those of trial situations.

The knowledge gaps that exist in the space between the varying approaches can assist with answering the **why** question. One of these gaps concerns the way in which *different forms of knowledge are communicated and interpreted within farming communities*, often organised around lead farmer and demonstration plot models by external organisations for the purpose of conservation agriculture promotion. It has been suggested that CA is a knowledge and management intensive agricultural technology, which might challenge its adoption in farming communities (Giller *et al.*, 2009; Wall, 2007). This requires examination of how agronomic knowledge is transferred within farming communities and if time will increase exposure and knowledge or if other factors are at play (Cheesman *et al.*, 2017; Fisher *et al.*, 2018; Holden *et al.*, 2018). The different stakeholders involved and the agronomic nature of this technical information requires both clusters to integrate for understanding these challenges and knowledge gaps. Furthermore, the processes through, which *CA principles and practices are experimented within and adapted* to different systems and different farm level priorities, requires an interdisciplinary study of the interactions between socio-economic and agronomic processes. Socio-economic studies can contribute to looking into the challenges such as ‘the mindset of the plough’ (Andersson & D’Souza, 2014) through understanding farmer decision-making, prioritization and contextual importance, but this also requires experimentation and learning around the biophysical performance of CA practices and principles. The framing conditions and disciplinary analysis build on the work by Andersson and D’Souza (2014), which highlighted the socio-economic and institutional conditions of CA adoption, and Giller et al. (2011), which considered the research gaps on different levels from field to regional. The explicit focus on disciplinary approaches and epistemologies, developed here, adds to mapping the framing conditions of CA literature and identifying the challenges to interdisciplinary and integrated analyses. It supports the previous laid out CA research agenda’s call for integrated and interdisciplinary studies (Giller *et al.*, 2011, 2015). Additionally, it enables us to make recommendations to specifically improve integrated and interdisciplinary approaches to understand ‘What works, where, for whom and why?’.

2.7 Recommendations for alternative and interdisciplinary approaches in addressing these knowledge gaps

To effectively address persistent knowledge gaps, new approaches are needed in studying **what forms of CA work, where, for whom, and why?** We acknowledge that farming systems are complex dynamic systems and that the discussion on farmers’ adoption of new agricultural innovations has been ongoing for decades (Biggs, 1989; Fujisaka, 1994), including challenges that can be described as ‘wicked’ problems (Batie, 2008; Rittel & Webber, 1973). This shows that tensions may persist between approaches and that it is unlikely to find one single solution. However, improving interdisciplinary approaches such as FSR can support addressing the identified knowledge gaps. Here we briefly outline three methodological recommendations for advancing research at the intersections between the socio-economic and agronomic research traditions that currently dominate CA research.

Our first recommendation is about the products and protocols of research. Collecting a broad range of variables within both socio-economic and agronomic research, and making this data widely available in consistent and comparable formats, through platforms such as the CGIAR CSA initiative can offer more scope for collating and integrating mixed data from a common context, to inform meta-analysis research (CCAFS, 2019). Because of the diversity and dynamic nature of farming systems, it is unrealistic for any individual research project to collect all possible variables over comprehensive spatial and temporal scales in order to fully validate comprehensive theories about CA. For this reason, there is real value in conducting meta-analyses across multiple datasets, which collectively better span the range of variables and scales. However, the strength of such analyses depends critically on the quality, compatibility and comprehensiveness of that collated data. Designing research with this in mind, with a view to making data accessible and computable for others, can contribute towards this broader endeavour of untangling and answering questions about what works, where, for whom and why. The yield data meta-regression by Steward et al. (2018) for example has illustrated the value of using collected data to answer the what and where parts of the question. To enable more meta-analyses like Steward et al. (2018), access to compatible, comprehensive and quality datasets is needed.

Secondly, we advocate for a methodological approach that draws strongly on a rich history of participation in farming systems research. Involving farmers and integrating local knowledges in the design and analysis of research across farming systems can contribute to a more thorough embedding of researching understandings of the local systems and broadening out of perspectives on why CA works (or does not work) in those contexts. To this end, there is value in advancing more ethnographic approaches to farming systems research. Ethnographic studies of innovation and technology development - termed technographic observation (Glover, 2011) - provide rich insights into the values, philosophies and priorities of individuals, as well as the processes of social interaction, exchange and knowledge creation, that underpin farming practices. Process of experimentation and adaptation of farming practices are dynamic and change over time, and resistance to new technologies may be similarly rooted in long histories. Such conditions may only be realised and fully understood through research that is embedded in societies and cultures over time. There are already examples of disciplines focusing on local understanding of often scientifically approached natural phenomena, such as the field of ethno-pedology which covers the indigenous classifications of soil and understanding of soil processes. Additionally, technographic observation as described in the case of SRI in Glover (2011) suggests asking more open-ended questions about new agricultural innovations, such as how it works in practice, and how this new knowledge flows into the current farmer practice systems. These kinds of approaches are the closest examples of bridging the ontological and epistemological perspectives described earlier.

Our third recommendation relates to the sites and structures of research. As a hybrid of controlled experimentation fields and household or community level research, we believe that on-farm experimentation and demonstration trials offer a valuable middle ground. This can contribute to achieving an interdisciplinary approach and potentially transdisciplinarity, where farmers are included in knowledge generation and interpretation. On-farm demonstration trials provide an opportunity to account for the more contextual information and data accepted in the agronomic research community (e.g., control fields, known quantities of herbicides and fertilizer) whereas the management by the farmer still allows for the community and cultural influence (Maat & Glover, 2012; Wall *et al.*, 2019). Research focused on on-farm demonstration trials is based on certain assumptions, such as the representativeness of on-farm trial results of new innovations for what farmers can accomplish on their own fields when the knowledge and experience is sufficient. These assumptions should be carefully handled and evaluated, but these trials offer the possibility to study multiple aspects, including technographic observation and their interactions around conservation agriculture.

The participation of farmers can take various forms depending on the aim and project phases. Biggs (1989) provide various examples of resource-poor farmer participation in research and describes four forms of participation: (1) contractual - farmers are contracted to provide a service or land; (2) consultative - farmers are consulted about their challenges which will feed into solution development; (3) collaborative - farmers and scientists are partners in the research; (4) collegial - the focus is to enhance informal development and research systems already in place. To increase participatory processes to answer **'what forms of CA work, where, for whom, and why?'**, it is important to tap into the informal research and development systems, local knowledge and extension systems. The collaborative and collegial mode provides the most potential for this. However, these forms of participation require understanding of institutional and political settings, and socio-economic barriers of participants and proper organisation of two-way communication is crucial (Biggs, 1989). Furthermore, the level of interaction of the different participants including biases in selection and roles, and meeting design (in addition to trials and surveys) is important for creating interdisciplinary and participatory research processes (Biggs, 1989). The presence of various disciplines does not automatically result in well-integrated studies. The management should enable timely iterative review and assessment of the goal relevant information (Biggs, 1989). An increasing involvement of social scientists and ethnography can provide valuable support to reaching this level of participation, organisation and integration.

It is important to note that on-farm trials can fall into specific discipline studies, and therefore, they are not the solution in itself. The work on on-farm trials provides an opportunity to incorporate different knowledge systems, incorporate control and complexity, and that can embrace quantitative and the qualitative methods. The CIMMYT on-farm trial literature such as Thierfelder et al. (2015a), Ngwira et al. (2012c) and Thierfelder et al. (2016a) shows the potential of examining biophysical, econometric and in the case of Thierfelder et al. (2015a) also socio-economic aspects around the on-farm demonstration trials. Another example is the mother-baby trial system in Snapp (2002) and Kerr et al. (2007), where a farmer research team supported by researchers maintained the mother trial with various legume technologies and 1–2 options were tested by individual farmers. There are different levels of farmer participation in on-farm research (Biggs, 1989). Whereas the CIMMYT trials are on the side of controlled researcher-designed trials, participatory action research (PAR) is a form of on-farm research where farmers are involved in the initial stages of research design and are included in repetitive cycles of research, reflection and action (Ernesto Méndez *et al.*, 2013, 2017). There is therefore potential to use the on-farm trials as middle ground for combining the approaches from different disciplines.

We believe that there is value in investing greater effort towards participatory and ethnographic research in and around on-farm experimentation and trial plots of CA, in order to understand how farmers engage with, interpret and contribute to contextualised knowledge processes. Interpreting this evidence within broader systematic analyses of consistent and comprehensive datasets, which cross socio-economic and agro-ecological variables and cross temporal and spatial scales, can contribute significantly to understanding what forms of CA work, where, why and for whom.

2.8 Conclusion

This analysis of the CA literature in Malawi has shown that there are two distinct approaches, namely agro-ecological and socio-economic, to addressing the question of **'what forms of CA work, where, and why?'** Neither of these approaches can address the full scope of this question on its own. The approaches are fundamentally different, which makes them incompatible and it impossible to just read across this literature in order to answer the question. For example, the controlled conditions and strictly defined practices that are used in controlled trials to understand the agronomic performance of CA do not reflect the messy and often fluid realities of how it is adapted and applied on farms. The agronomic arguments do not necessarily translate well. Equally, the lack of systematic, replicable documentation of agronomic conditions, practices and performance in research on farming communities means that it is difficult to scale out our understanding of what works where and why, beyond the confines of the trial site.

Some of the knowledge gaps exist in the space between these two approaches. Examples are our understanding of how knowledge and information are constructed and communicated across scales, and how different and contextualised knowledges shape on-farm decision making around the adoption and adaptation of CA. We suggest that on-farm trials provide an opportunity for decreasing the space between different approaches and increase the connectivity of studies from across different disciplinary realms. Approaches such as technographic observations around these on-farm trials can provide a new approach that includes both the technical and social aspects of the CA studies. The on-farm trial provides a promising space for interdisciplinary epistemology and ontology, which incorporate different knowledge systems, qualitative and quantitative methods, control and complexity. Interpreting findings from integrated studies within broader meta-analyses of comprehensive and cross-scale datasets will help us to better understand what forms of CA work, where, for whom and, crucially, why.

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References

Andersson JA, D'Souza S. 2014. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment* 187: 116–132. DOI: 10.1016/j.agee.2013.08.008

Andersson JA, Giller KE. 2012. On heretics and God's blanket salesmen : Contested claims for Conservation Agriculture and the politics of its promotion in African smallholder farming. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World.* Earthscan, Routledge: Abingdon, Oxon, 22–46. DOI: 10.4324/9780203125434

Antwi-Agyei P, Dougill AJ, Stringer LC. 2015. Barriers to climate change adaptation: evidence from northeast Ghana in the context of a systematic literature review. *Climate and Development* 7: 297–309. DOI: 10.1080/17565529.2014.951013

Asfaw S, Orecchia C, Pallante G, Palma A. 2018. *Soil and nutrients loss in Malawi: an economic assessment.* , 1–88

Batie SS. 2008. Wicked problems and applied economics. *American Journal of Agricultural Economics* 90: 1176–1191. DOI: 10.1111/j.1467-8276.2008.01202.x

Bell AR, Cheek JZ, Mataya F, Ward PS. 2018. Do as they did: Peer effects explain adoption of conservation agriculture in Malawi. *Water (Switzerland)* 10: 51. DOI: 10.3390/w10010051

Biesbroek GR, Klostermann JEM, Termeer CJAM, Kabat P. 2013. On the nature of barriers to climate change adaptation. *Regional Environmental Change* 13: 1119–1129. DOI: 10.1007/s10113-013-0421-y

Biggs SD. 1989. *Resource-Poor Farmer Participation in Research: A Synthesis of Experiences from Nine National Agricultural Research Systems.* The Hague, Netherlands

Black J. 1998. Regulation as Facilitation: Negotiating the Genetic Revolution. *Modern Law Review* 61: 621–660. DOI: 10.1111/1468-2230.00171

Black J. 2002. Regulatory Conversations. *Journal of Law and Society* 29: 163–196. DOI: 10.1111/1467-6478.00215

Brown B, Llewellyn R, Nuberg I. 2018a. Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa. *Global Food Security* 17: 213–220. DOI: 10.1016/j.gfs.2017.10.002

Brown B, Nuberg I, Llewellyn R. 2017. Negative evaluation of conservation agriculture: perspectives from African smallholder farmers. *International Journal of Agricultural Sustainability* 15: 467–481. DOI: 10.1080/14735903.2017.1336051

Brown B, Nuberg I, Llewellyn R. 2018b. Constraints to the utilisation of conservation agriculture in Africa as perceived by agricultural extension service providers. *Land Use Policy* 73: 331–340. DOI: 10.1016/j.landusepol.2018.02.009

Brown B, Nuberg I, Llewellyn R. 2018c. Research capacity for local innovation: the case of conservation agriculture in Ethiopia, Malawi and Mozambique. *Journal of Agricultural Education and Extension* 24: 249–262. DOI: 10.1080/1389224X.2018.1439758

Bunderson WT, Jere ZD, Thierfelder C, Gama M, Mwale BM, Ng'oma SWD, Museka RM, Paul JM, Mbale B, Mkandawire O, Tembo P. 2017. Implementing the Principles of Conservation Agriculture in Malawi: Crop Yields and Factors Affecting Adoption. In: Kassam AH, Mkomwa S and Friedrich T (eds) *Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate.* CABI: Wallingford, UK, 75–99

Bünemann EK, Bongiorno G, Bai Z, Creamer RE, De Deyn G, de Goede R, Fleskens L, Geissen V, Kuyper TW, Mäder P, Pulleman M, Sukkel W, van Groenigen JW, Brussaard L. 2018. Soil quality – A critical review. *Soil Biology and Biochemistry* 120: 105–125. DOI: 10.1016/j.soilbio.2018.01.030

CCAFS. 2019. *Climate-Smart Technologies and Practices | CCAFS: CGIAR research program on Climate Change, Agriculture and Food Security.*

Cheesman S, Andersson JA, Frossard E. 2017. Does closing knowledge gaps close yield gaps? On-farm conservation agriculture trials and adoption dynamics in three smallholder farming areas in Zimbabwe. *Journal of Agricultural Science* 155: 81–100. DOI: 10.1017/S0021859616000095

Cheesman S, Thierfelder C, Eash NS, Kassie GT, Frossard E. 2016. Soil carbon stocks in conservation agriculture systems of Southern Africa. *Soil and Tillage Research* 156: 99–109. DOI: 10.1016/j.still.2015.09.018

Chinseu E, Dougill A, Stringer L. 2019. Why do smallholder farmers dis-adopt conservation agriculture? Insights from Malawi. *Land Degradation and Development* 30: 533–543. DOI: 10.1002/ldr.3190

Collinson M. 2000. *A history of farming systems research*. CABI: Wallingford, UK

Crotty M. 1998. *The Foundations of Social Research Meaning and Perspective in the Research Process.* SAGE: London

Dougill AJ, Whitfield S, Stringer LC, Vincent K, Wood BT, Chinseu EL, Steward PR, Mkwambisi D. 2017. Mainstreaming conservation agriculture in Malawi: Knowledge gaps and institutional barriers. *Journal of Environmental Management* 195: 25–34. DOI: 10.1016/j.jenvman.2016.09.076

Ernesto Méndez V, Bacon CM, Cohen R. 2013. Agroecology as a transdisciplinary, participatory, and action-oriented approach. *Agroecology and Sustainable Food Systems*, 3–18. DOI: 10.1080/10440046.2012.736926

Ernesto Méndez V, Caswell M, Gliessman SR, Cohen R. 2017. Integrating agroecology and participatory action research (PAR): Lessons from Central America. *Sustainability* 9: 1–19. DOI: 10.3390/su9050705

FAO. 2008. *Investing in sustainable agricultural intensification. The role of conservation agriculture. Food and Agriculture Organization of the United Nations.* Rome, Italy.

FAO. 2015. *Conservation Agriculture*. http://www.fao.org/conservation-agriculture/en/

Fisher M, Holden ST, Thierfelder C, Katengeza SP. 2018. Awareness and adoption of conservation agriculture in Malawi: what difference can farmer-to-farmer extension make? *International Journal of Agricultural Sustainability* 16: 310–325. DOI: 10.1080/14735903.2018.1472411

Fujisaka S. 1994. Learning from six reasons why farmers do not adopt innovations intended to improve sustainability of upland agriculture. *Agricultural Systems* 46: 409–425. DOI: 10.1016/0308-521X(94)90104-N

Giller KE, Andersson JA, Corbeels M, Kirkegaard J, Mortensen D, Erenstein O, Vanlauwe B. 2015. Beyond conservation agriculture. *Frontiers in Plant Science* 6: 1–14. DOI: 10.3389/fpls.2015.00870

Giller KE, Corbeels M, Nyamangara J, Triomphe B, Affholder F, Scopel E, Tittonell P. 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. *Field Crops Research* 124: 468–472. DOI: 10.1016/j.fcr.2011.04.010

Giller KE, Witter E, Corbeels M, Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* 114: 23–34. DOI: 10.1016/j.fcr.2009.06.017

Glaser BG, Strauss AL. 1967. *The Discovery of Grounded Theory: Strategies for Qualitative Research.* AldineTransaction: New Brunswick, USA. DOI: 10.2307/2094063

Glover D. 2011. The System of Rice Intensification: Time for an empirical turn. NJAS - Wageningen *Journal of Life Sciences* 57: 217–224. DOI: 10.1016/j.njas.2010.11.006

Grabowski PP, Kerr JM, Haggblade S, Kabwe S. 2016. Determinants of adoption and disadoption of minimum tillage by cotton farmers in eastern Zambia. *Agriculture, Ecosystems and Environment* 231: 54–67. DOI: 10.1016/j.agee.2016.06.027

Holden ST, Fisher M, Katengeza SP, Thierfelder C. 2018. Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land Use Policy* 76: 113–123. DOI: 10.1016/j.landusepol.2018.04.048

IBM Corp. 2015. IBM SPSS Statistics for Windows, Version 23.0. IBM Corp: Armonk, NY

Johansen C, Haque ME, Bell RW, Thierfelder C, Esdaile RJ. 2012. Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. *Field Crops Research* 132: 18–32. DOI: 10.1016/j.fcr.2011.11.026

Kaluzi L, Thierfelder C, Hopkins DW. 2017. Smallholder Farmer Innovation and Contexts in Maize-Based Conservation Agriculture Systems in Central Malawi. *Sustainable Agriculture Research* 6: 85. DOI: 10.5539/sar.v6n3p85

Kassam A, Friedrich T, Derpsch R. 2019. Global spread of Conservation Agriculture. International *Journal of Environmental Studies* 76: 29–51. DOI: 10.1080/00207233.2018.1494927

Kassam A, Friedrich T, Shaxson F, Pretty J. 2009. The spread of Conservation Agriculture: justification, sustainability and uptake. *International Journal of Agricultural Sustainability* 7: 292–320. DOI: 10.3763/ijas.2009.0477

Kerr RB, Snapp S, Chirwa M, Shumba L, Msachi R. 2007. Participatory research on legume diversification with Malawian smallholder farmers for improved human nutrition and soil fertility. *Experimental Agriculture* 43: 437–453. DOI: 10.1017/S0014479707005339

Khataza RRB, Doole GJ, Kragt ME, Hailu A. 2018. Information acquisition, learning and the adoption of conservation agriculture in Malawi: A discrete-time duration analysis. *Technological Forecasting and Social Change* 132: 299–307. DOI: 10.1016/J.TECHFORE.2018.02.015

Leach M, Scoones I, Stirling A. 2010. *Dynamic Sustainabilities: Technology, Environment, Social Justice.* Earthscan: Abingdon, Oxon

Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen PT, Sessa R, Shula R, Tibu A, Torquebiau EF. 2014. Climate-smart agriculture for food security. *Nature Climate Change* 4: 1068–1072. DOI: 10.1038/nclimate2437

Maat H, Glover D. 2012. Alternative Configurations of agronomic experimentation. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World.* Routledge: Abingdon, Oxon, 131–145

Makate C, Makate M, Mango N, Siziba S. 2019. Increasing resilience of smallholder farmers to climate change through multiple adoption of proven climate-smart agriculture innovations. Lessons from Southern Africa. *Journal of Environmental Management* 231: 858–868. DOI: 10.1016/j.jenvman.2018.10.069

Mloza-Banda HR, Makwiza CN, Mloza-Banda ML. 2016. Soil properties after conversion to conservation agriculture from ridge tillage in Southern Malawi. *Journal of Arid Environments* 127: 7–16. DOI: 10.1016/j.jaridenv.2015.11.001

Mloza-Banda ML, Cornelis WM, Mloza-Banda HR, Makwiza CN, Verbist K. 2014. Soil properties after change to conservation agriculture from ridge tillage in sandy clay loams of mid-altitude Central Malawi. *Soil Use and Management* 30: 569–578. DOI: 10.1111/sum.12139

Moon K, Blackman D. 2014. A Guide to Understanding Social Science Research for Natural Scientists. *Conservation Biology* 28: 1167–1177. DOI: 10.1111/cobi.12326

Mupangwa W, Mutenje M, Thierfelder C, Nyagumbo I. 2017a. Are conservation agriculture (CA) systems productive and profitable options for smallholder farmers in different agro-ecoregions of Zimbabwe? Renewable *Agriculture and Food Systems* 32: 87–103. DOI: 10.1017/S1742170516000041

Mupangwa W, Thierfelder C, Ngwira AR. 2017b. Fertilization strategies in conservation agriculture systems with maize-legume cover crop rotations in Southern Africa. *Experimental Agriculture* 53: 288–307. DOI: 10.1017/S0014479716000387

Mutenje MJ, Farnworth CR, Stirling C, Thierfelder C, Mupangwa W, Nyagumbo I. 2019. A cost-benefit analysis of climate-smart agriculture options in Southern Africa: Balancing gender and technology. *Ecological Economics* 163: 126–137. DOI: 10.1016/j.ecolecon.2019.05.013

Ndah HT, Schuler J, Uthes S, Zander P, Traore K, Gama M-SM-S, Nyagumbo I, Triomphe B, Sieber S, Corbeels M. 2014. Adoption potential of conservation agriculture practices in Sub-Saharan Africa: Results from five case studies. *Environmental Management* 53: 620–635. DOI: 10.1007/s00267-013-0215-5

Ngwira AR, Aune JB, Mkwinda S. 2012a. On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research* 132: 149–157. DOI: 10.1016/j.fcr.2011.12.014

Ngwira AR, Aune JB, Thierfelder C. 2014a. On-farm evaluation of the effects of the principles and components of conservation agriculture on maize yield and weed biomass in malawi. *Experimental Agriculture* 50: 591–610. DOI: 10.1017/S001447971400009X

Ngwira AR, Johnsen FH, Aune JB, Mekuria M, Thierfelder C. 2014b. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. *Journal of Soil and Water Conservation* 69: 107–119. DOI: 10.2489/jswc.69.2.107

Ngwira AR, Sleutel S, de Neve S. 2012b. Soil carbon dynamics as influenced by tillage and crop residue management in loamy sand and sandy loam soils under smallholder farmers' conditions in Malawi. *Nutrient Cycling in Agroecosystems* 92: 315–328. DOI: 10.1007/s10705-012-9492-2

Ngwira AR, Thierfelder C, Eash NS, Lambert DM. 2013. Risk and Maize-Based Cropping Systems for Smallholder Malawi Farmers Using Conservation Agriculture Technologies. *Experimental Agriculture* 49: 483–503. DOI: 10.1017/S0014479713000306

Ngwira AR, Thierfelder C, Lambert DM. 2012c. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems* 28: 350–363. DOI: 10.1017/S1742170512000257

Nyagumbo I, Mkuhlani S, Pisa C, Kamalongo D, Dias D, Mekuria M. 2016. Maize yield effects of conservation agriculture based maize–legume cropping systems in contrasting agro-ecologies of Malawi and Mozambique. *Nutrient Cycling in Agroecosystems* 105: 275–290. DOI: 10.1007/s10705-015-9733-2

Pannell DJ, Llewellyn RS, Corbeels M. 2014. The farm-level economics of conservation agriculture for resource-poor farmers. *Agriculture, Ecosystems and Environment* 187: 52–64. DOI: 10.1016/j.agee.2013.10.014

Rittel HWJ, Webber MM. 1973. Dilemmas in a General Theory of Planning. *Policy Sciences* 4: 155–169. DOI: https://doi.org/10.1007/BF01405730

Snapp SS. 2002. Quantifying farmer evaluation of technologies: The mother and baby trial design. In: Bellon MR and Reeves J (eds) *Quantitative Analysis of Data from Participatory Methods in Plant Breeding.* CIMMYT, PRGA and IRRI: Mexico,DF, 9–18

Stevenson JR, Serraj R, Cassman KG. 2014. Evaluating conservation agriculture for small-scale farmers in Sub-Saharan Africa and South Asia. *Agriculture, Ecosystems and Environment* 187: 1–10. DOI: 10.1016/j.agee.2014.01.018

Steward PR, Dougill AJ, Thierfelder C, Pittelkow CM, Stringer LC, Kudzala M, Shackelford GE. 2018. The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments : A meta-regression of yields. *Agriculture, Ecosystems and Environment* 251: 194–202. DOI: 10.1016/j.agee.2017.09.019

Sumberg J, Thompson J, Woodhouse P. 2012. *Contested Agronomy: Agricultural research in a changing world.* Earthscan, Routledge: Abingdon, Oxon

TerAvest D, Carpenter-Boggs L, Thierfelder C, Reganold JP. 2015. Crop production and soil water management in conservation agriculture, no-till, and conventional tillage systems in Malawi. *Agriculture, Ecosystems and Environment* 212: 285–296. DOI: 10.1016/j.agee.2015.07.011

TerAvest D, Wandschneider PR, Thierfelder C, Reganold JP. 2019. Diversifying conservation agriculture and conventional tillage cropping systems to improve the wellbeing of smallholder farmers in Malawi. *Agricultural Systems* 171: 23–35. DOI: 10.1016/j.agsy.2019.01.004

Tesfaye K, Jaleta M, Jena P, Mutenje M. 2015. Identifying Potential Recommendation Domains for Conservation Agriculture in Ethiopia, Kenya, and Malawi. *Environmental Management* 55: 330–346. DOI: 10.1007/s00267-014-0386-8

The World Bank. 2016. *Rural population (% of total population) | Data.*

Thierfelder C, Bunderson WT, Jere ZD, Mutenje M, Ngwira AR. 2016a. Development of Conservation Agriculture (Ca) Systems in Malawi: Lessons Learned From 2005 To 2014. *Experimental Agriculture* 52: 579–604. DOI: 10.1017/S0014479715000265

Thierfelder C, Bunderson WT, Mupangwa W. 2015a. Evidence and Lessons Learned from Long-Term On-Farm Research on Conservation Agriculture Systems in Communities in Malawi and Zimbabwe. *Environments* 2: 317–337. DOI: 10.3390/environments2030317

Thierfelder C, Cheesman S, Rusinamhodzi L. 2013a. Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa. International *Journal of Agricultural Sustainability* 11: 108–124. DOI: 10.1080/14735903.2012.703894

Thierfelder C, Chisui JL, Gama M, Cheesman S, Jere ZD, Trent Bunderson W, Eash NS, Rusinamhodzi L. 2013b. Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. *Field Crops Research* 142: 47–57. DOI: 10.1016/j.fcr.2012.11.010

Thierfelder C, Chivenge P, Mupangwa W, Rosenstock TS, Lamanna C, Eyre JX. 2017. How climate-smart is conservation agriculture (CA)? – its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Security* 9: 537–560. DOI: 10.1007/s12571-017-0665-3

Thierfelder C, Matemba-Mutasa R, Bunderson WT, Mutenje M, Nyagumbo I, Mupangwa W. 2016b. Evaluating manual conservation agriculture systems in southern Africa. *Agriculture, Ecosystems and Environment* 222: 112–124. DOI: 10.1016/j.agee.2016.02.009

Thierfelder C, Matemba-Mutasa R, Rusinamhodzi L. 2015b. Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. *Soil and Tillage Research* 146: 230–242. DOI: 10.1016/j.still.2014.10.015

Thierfelder C, Mombeyarara T, Mango N, Rusinamhodzi L. 2013c. Integration of conservation agriculture in smallholder farming systems of southern Africa: Identification of key entry points. International *Journal of Agricultural Sustainability* 11: 317–330. DOI: 10.1080/14735903.2013.764222

Thierfelder C, Rusinamhodzi L, Ngwira AR, Mupangwa W, Nyagumbo I, Kassie GT, Cairns JE. 2015c. Conservation agriculture in Southern Africa: Advances in knowledge. *Renewable Agriculture and Food Systems* 30: 328–348. DOI: 10.1017/S1742170513000550

Thierfelder C, Wall PC. 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil and Tillage Research* 105: 217–227. DOI: 10.1016/j.still.2009.07.007

Thierfelder C, Wall PC. 2010a. Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. *Journal of Crop Improvement* 24: 113–121. DOI: 10.1080/15427520903558484

Thierfelder C, Wall PC. 2010b. Rotation in Conservation Agriculture Systems of Zambia: Effects on Soil Quality and Water Relations. *Experimental Agriculture* 46: 309–325. DOI: 10.1017/S001447971000030X

Thompson HE, Berrang-Ford L, Ford JD. 2010. Climate change and food security in Sub-Saharan Africa: A systematic literature review. *Sustainability* 2: 2719–2733. DOI: 10.3390/su2082719

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gérard B, Rufino MC, Teufel N, van Rooyen A, van Wijk MT. 2012. Conservation Agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research* 132: 175–184. DOI: 10.1016/j.fcr.2012.02.022

Vogel H. 1994. Weeds in single-crop conservation farming in Zimbabwe. *Soil and Tillage Research* 31: 169–185. DOI: 10.1016/0167-1987(94)90078-7

Wall PC. 2007. Tailoring Conservation Agriculture to the Needs of Small Farmers in Developing Countries: An Analysis of Issues. *Journal of Crop Improvement* 1938: 137–155. DOI: 10.1300/J411v19n01_07

Wall PC, Thierfelder CL, Nyagumbo I, Rusinamhodzi L, Mupangwa W. 2019. Comment on "De Roo et al. (2019). On-farm trials for development impact? the organization of research and the scaling of agricultural technologies." *Experimental Agriculture* 55: 185–194. DOI: 10.1017/S0014479718000492

Ward JH. 1963. Hierarchical Grouping to Optimize an Objective Function. *Journal of the American Statistical Association* 58: 236–244. DOI: 10.1080/01621459.1963.10500845

Ward PS, Bell AR, Droppelmann K, Benton TG. 2018. Early adoption of conservation agriculture practices: Understanding partial compliance in programs with multiple adoption decisions. *Land Use Policy* 70: 27–37. DOI: 10.1016/j.landusepol.2017.10.001

Ward PS, Bell AR, Parkhurst GM, Droppelmann K, Mapemba L. 2016. Heterogeneous preferences and the effects of incentives in promoting conservation agriculture in Malawi. *Agriculture, Ecosystems and Environment* 222: 67–79. DOI: 10.1016/j.agee.2016.02.005

Whitfield S. 2015. *Adapting to Climate Uncertainty in African Agriculture: Narratives and Knowledge Politics.* Earthscan, Routledge: Abingdon, Oxon. DOI: 10.4324/9781315725680

Whitfield S, Dixon JL, Mulenga BP, Ngoma H. 2015a. Conceptualising farming systems for agricultural development research: Cases from Eastern and Southern Africa. *Agricultural Systems* 133: 54–62. DOI: 10.1016/j.agsy.2014.09.005

Whitfield S, Dougill AJ, Dyer JC, Kalaba FK, Leventon J, Stringer LC. 2015b. Critical reflection on knowledge and narratives of conservation agriculture. *Geoforum* 60: 133–142. DOI: 10.1016/j.geoforum.2015.01.016

Chapter 3

Combining local knowledge and soil science for integrated soil health assessments in Conservation Agriculture systems

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Abstract

The challenges of soil degradation and climate change have led to the emergence of Conservation Agriculture (CA) as a sustainable alternative to tillage-based agriculture systems. Despite the recognition of positive impacts on soil health, CA adoption in Africa has remained low. Previous soil health studies have mainly focused on 'scientific' measurements, without consideration of local knowledge, which influences how farmers interpret CA impacts and future land management decisions. This study, based in Malawi, aims to 1) combine local knowledge and conventional soil science approaches to develop a contextualised understanding of the impact of CA on soil health; and 2) understand how an integrated approach can contribute to explaining farmer decision-making on land management. Key farmers' indicators of soil health were crop performance, soil consistence, moisture content, erosion, colour, and structure. These local indicators were consistent with conventional soil health indicators. By combining farmers' observations with soil measurements, we observed that CA improved soil structure, moisture (Mwansambo 7.54%–38.15% lower for CP; Lemu 1.57%–47.39% lower for CP) and infiltration (Lemu CAM/CAML 0.15 cms$^{-1,}$ CP 0.09 cms^{-1}; Mwansambo CP/CAM 0.14 cms^{-1}, CAML 0.18 cms^{-1}). In the conventional practice, farmers perceived ridges to redistribute nutrients, which corresponded with recorded higher exchangeable ammonium (Lemu CP 76.0 mgkg^{-1}, CAM 49.4 mgkg^{-1}, CAML 51.7 mgkg^{-1}), nitrate/nitrite values (Mwansambo CP 200.7 mgkg^{-1}, CAM 171.9 mgkg^{-1}, CAML 103.3 mgkg^{-1}). This perception contributes to the popularity of ridges, despite the higher yield measurements under CA (Mwansambo CP 3225 kgha^{-1}, CAML 5067 kgha^{-1}, CAM 5160 kgha^{-1}; Lemu CP 2886 kgha^{-1}, CAM 2872 kgha^{-1}, CAML 3454 kgha^{-1}). The perceived carbon benefits of residues and ridge preference has promoted burying residues in ridges. Integrated approaches contribute to more nuanced and localized perceptions about land management. We propose that the stepwise integrated soil assessment framework developed in this study can be applied more widely in understanding the role of soil health in farmer-decision

making, providing a learning process for downscaling technologies and widening the evidence base on sustainable land management practices.

Keywords: Climate-Smart Agriculture, southern Africa, No-tillage, Malawi, Soil Health, Local Knowledge

3.1 Introduction

In response to challenges of climate change and increasing soil degradation, Conservation Agriculture (CA) is being widely promoted across sub-Saharan Africa (SSA) as a form of climate-smart agriculture. CA is characterized by three key practices of minimum soil disturbance, continuous organic soil cover, and crop diversification through rotation or intercropping (FAO, 2015). Regional studies on CA performance compared to conventional practices have shown improvements in soil water retention (Thierfelder *et al.*, 2015b; Thierfelder & Wall, 2010), infiltration capacity (Ngwira *et al.*, 2012b; Thierfelder *et al.*, 2015b; Thierfelder & Wall, 2010), soil structure (Eze *et al.*, 2020), biological activity (Ngwira *et al.*, 2012b; Thierfelder *et al.*, 2015b), crop yields (Ngwira *et al.*, 2012b) and heat stress resilience (Steward *et al.*, 2018). Therefore, CA systems are being promoted by governments and international organizations citing its potential to improve soil health and to increase or sustain yield in the long-term. However, the CA adoption rate across SSA remains low, for example in Malawi CA covers only 5.6% of the arable land (Kassam *et al.*, 2019).

Various reasons for slow CA adoption have been documented, such as lack of sufficient residues or resources (Andersson & D'Souza, 2014; Giller *et al.*, 2009). There has been a lack of local participation in the design of management practices and impact assessment of externally recommended practices. The absence of sufficient 'scientific' data on performance of CA in different climatic areas, farming conditions and on the livelihood benefits experienced makes some researchers question its widespread promotion (e.g., Giller et al., 2009). In particular, examination of the individual impacts of different CA principles on site-specific soil and climatic conditions is required to more holistically understand the benefits of CA. Whereas most studies on soil health have concentrated on 'scientific' measurements, local knowledge can also contribute to this understanding by providing reflection on local processes and outcomes. The importance and value of local knowledge or mixed hybrid knowledge in fields such as soil, and environmental science has been widely published (Mairura *et al.*, 2007; Oppenheimer *et al.*, 2014; Prudat *et al.*, 2018; Raymond *et al.*, 2010). Including this knowledge in the process of analysing the impacts of CA ensures the assessment is embedded in the farming context, thereby contributing to improved understanding of farmers' decision-making and the role of soil health knowledge in land management decisions. This can support the scaling, in particular downscaling, adoption and adaptation of technology and land management practice.

On-farm trials represent an opportunity to bridge local and scientific knowledge through a participatory and integrated methodological approach (Hermans et al., 2020a). Baudron et al. (2011) highlighted that evidence for CA benefits is often based on controlled research station studies and working on-farm in collaboration with farming communities opens an avenue for knowledge exchange. A combination of participatory and scientific methods can address the call for CA research to use a systems perspective with an interdisciplinary, integrative and participatory bottom-up approach (Andersson & D'Souza, 2014; Giller *et al.*, 2011; Whitfield *et al.*, 2014). Combining conventional soil health knowledge embedded in scientific literature and local knowledge can contribute to our overall understanding of CA performance and the processes explaining observed outcomes ('why does it work here?').

3.1.1 Soil health background

The soil improvement narrative of CA raises the need to discuss the meaning of soil quality and soil health, often used interchangeably. Soil quality refers to the capacity of a specific kind of soil to function within ecosystem boundaries to support a particular use such as crop production (Laishram *et al.*, 2012). Conversely, soil health refers more broadly to the capacity of soil to function as a living system to support plant, animal and human life (Laishram *et al.*, 2012). In the context of CA, soil improvement is related to the benefit to human life through increasing food and nutrition security, environmental quality as well as climate change resilience. This conforms most closely with the concept of soil health.

Soil health or soil quality cannot be measured directly, they are concepts for examining functions and relationships between biological, physical and chemical soil parameters important for sustainable agriculture (Karlen *et al.*, 1997). To transfer from a conceptual definition to measurable soil health a minimum dataset (MDS) of measurable soil parameters has been suggested, including biological, physical and chemical soil parameters (Arshad & Coen, 1992; Bünemann *et al.*, 2018; Carter *et al.*, 1997; Govaerts *et al.*, 2006; Gregorich *et al.*, 1994; Laishram *et al.*, 2012; Singer & Ewing, 2000). The most popular MDS of soil health indicators are presented in Table 3.1. The selection of MDS is guided by those parameters that 1) indicate sensitivity to soil management, 2) can inform land management decisions, and 3) contribute to an understanding of soil system processes; and 4) are readily measurable (Karlen *et al.*, 1997; Laishram *et al.*, 2012; Parisi *et al.*, 2005).

Table 3.1 Minimum data set (MDS) for soil quality and health assessments based on Laishram et al. (2012) (Arshad & Coen, 1992; Carter et al., 1997; Govaerts et al., 2006; Gregorich et al., 1994; Laishram et al., 2012; Singer & Ewing, 2000)

Key soil health parameters	Reason
Organic Matter	Important for soil structure and fertility, and water holding capacity
N forms in soil	Mineralization and immobilization rates, support soil fertility, leaching
Extractable K, N, and P	Potential of nutrients to support plant development
Aggregation	Indicator of soil structure and erosion protection
Texture	Important for soil water and nutrient transfer and retention
Bulk Density	Porosity, adaptation to soil volume
Depth to hardpan	Roots growth potential
pH	Availability of nutrients
Electrical conductivity	Connection to soil structure, infiltration and crop development
Potential pollutants	Potential for plant growth and plant-soil system health
Soil respiration	Indicator for biological activity and organic matter
Infiltration	Indicator for erosion and run off
Water-holding capacity	Sufficient moisture to support plant growth

MDS soil parameters have been used for assessing the impact of CA on soil health, in particular in relation to organic matter content and hydraulic dynamics. The improvement of hydraulic dynamics (e.g., infiltration and water holding capacity as defined in the MDS) is one of the most important benefits attributed to CA management in terms of soil health improvement (Thierfelder & Wall, 2009). The CA literature has shown that the conventional ridge and furrow system decreases water retention, especially during dry and hot spells, and increases moisture loss on uncovered soil due to tillage increasing the soil surface area (Thierfelder *et al.*, 2013; Thierfelder & Wall, 2009). CA impacts on soil hydraulic properties are influenced by site specific factors such as soil texture and are more apparent on sandy soils (Steward *et al.*, 2018).

Various studies on research stations in Zimbabwe, Zambia and Malawi have shown that carbon (C) stocks, the quantity of C per unit area, increased under CA treatments relative to conventional practices (Ligowe *et al.*, 2017; Thierfelder *et al.*, 2012) (0–10 cm, 10–20 cm, 0–30 cm depth). However, results from on-farm trials in Malawi have recorded both insignificant (Cheesman *et al.*, 2016) and significant differences in soil C stocks and concentrations (Mloza-Banda *et al.*, 2016, 2014; Ngwira *et al.*, 2012a). These inconsistencies have also been reported in other locations across Sub-Saharan Africa (Powlson *et al.*, 2016). Another key chemical soil health indicator, is total nitrogen (N). Only a few CA studies have looked at different forms of N (Mloza-Banda *et al.*, 2016, 2014; Ngwira *et al.*, 2012a), and very little has been done in Malawi to examine plant available N. The meta-regression by Steward et al. (2018) showed that CA outperforms conventional treatments when there is high heat stress and low N fertilizer application. Therefore, research on the impact of CA on C stocks and total N concentrations has provided mixed results, depending on site specific temporal and spatial conditions.

In most CA soil health studies only quantitative parameters have been considered and qualitative indicators embedded in farmers' knowledge have received little attention. As an exception, Mairura et al. (2007) used data based on farmers' perceptions in central Kenya and showed that local soil knowledge was beneficial for soil health assessment and that visual soil improvement is central in farmers' assessments. Similarly, a participatory approach to soil quality assessment in Namibia showed that integrating long-term local knowledge and short term technical knowledge can address soil quality assessment limits on temporal scales (Prudat *et al.*, 2018). This suggests that an integrated approach to soil health evaluation, combining local and scientific knowledge, can enrich understanding of the impact of agricultural practices on soil health.

3.1.2 Aim & research questions

This paper develops and applies an integrated assessment approach, which combines local knowledge with conventional scientific soil measurements to evaluate soil health impacts of CA (Mairura *et al.*, 2007; Prudat *et al.*, 2018) and its role in farmers' decision-making in Malawi. The term local knowledge is used due to its wider conceptual application, meaning all related knowledge about the surroundings and context over time by people in an area (Trogrlić *et al.*, 2019). This study approaches soil health from a farmer's perspective in two case study regions, and uses this to develop and test a set of yield and soil measurements based on a soil health minimum dataset covering soil C, N, infiltration, moisture, structure and bulk density.

The paper addresses two main research questions:

1) What is the contextualised understanding of the impact of CA on soil health at on-farm trial sites in Malawi, based on learning across local knowledge and conventional soil science approaches?

2) In what ways can an integrated knowledge and methods approach contribute to assessing the impact of CA on soil health and understanding related farmer decision-making on land management?

We hypothesize that the combination of local knowledge and conventional soil science provides a broader evidence base for the outcomes of CA and contributes to a better understanding of farmer decision-making around the practice of CA.

We first provide the research design and taken approach including the stepwise integrated soil assessment framework. The results are presented according to the stepwise framework: Section 3.3.1 Farmers' Soil Health Indicators, Section 3.3.2 Quantitative Soil Health Indicator Selection, and Section 3.3.3 Quantitative Soil Health Measurements. The remainder of the paper discusses the soil health indicator measurements (Section 3.4.1), and the integrated approach for soil health assessment (Section 3.4.2).

3.2 Research design

3.2.1 Study area and on-farm trial design

The study was carried out at two medium-term CA on-farm trial sites in Malawi: Mwansambo in the central region and Lemu in the southern region (Figure 3.1; Table 3.2).

Each on-farm trial has three main treatments as described and explained previously by Ngwira et al. (2012b) and Thierfelder et al. (2015a). The treatments are as follows:

1) Conventional practice with ridge and furrow system (CP) prepared with a hand hoe in September or October with crop residues removed after harvest.

2) Conservation agriculture with sole maize (CAM). In this treatment there is no tillage and maize is planted with a dibble stick (one hole for seed and one for fertilizer). Residues are retained as surface mulch.

3) Conservation agriculture with maize and legume intercrop (CAML): cowpea (*Vigna unguiculata* L.) in Mwansambo and pigeon pea (*Cajanus Cajan* L.) in Lemu. Crops are planted with a dibble stick and have similar no tillage and crop residue treatment as CAM.

All plots are rotated annually with groundnuts (*Arachis hypogaea* L.) planted on ridges in CP and on the flat in CAM and CAML. Details on trial management can be found in Appendix C.1.

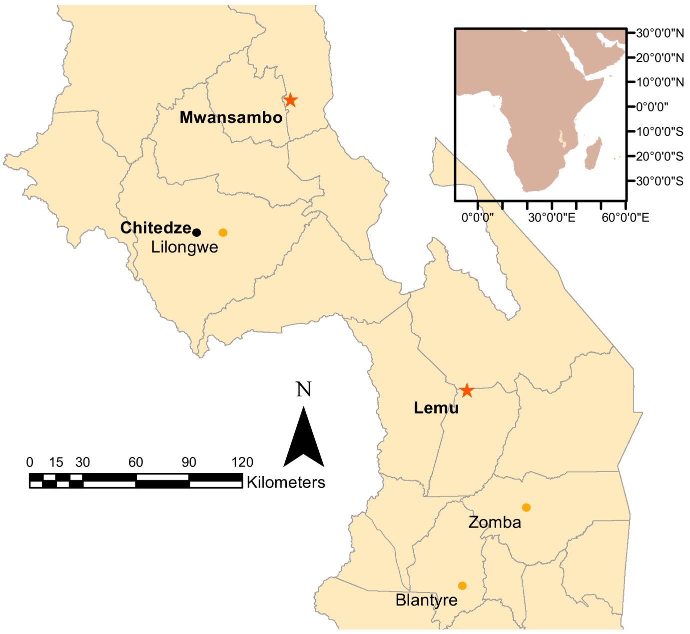

Figure 3.1 Map showing the study sites in Malawi: Mwansambo and Lemu.

Table 3.2 Study sites description

Site Characteristics	**Site**	
	Mwansambo	**Lemu**
On-farm Trials	6	6
Latitude (°)	-13.32	-14.79
Longitude (°)	34.11	35.00
Altitude (masl)	665	735
Soil type	Haplic Lixisols	Chromic Luvisols
Soil Texture	Sandy Clay Loam	Sandy Loam
Rainfall (mm)	1330-1359	605-1226
Year CA started	2005	2007
Farming System	Maize mixed	Maize mixed
Land holding (ha)	0.5	0.4
Population	229,460 (71/km^2)	310,000 (145/km^2)
Distance to Market (km)	30	30
Extension	Total LandCare (TLC)	Machinga ADD (Gov)
Lineage Majority	Patrilineal	Matrilineal

3.2.2 Integrated assessment of soil health

The approach taken to evaluate soil health impacts of CA consisted of a sequential process that involved:

(1) discussing CA's impact on soil health with farmers;

(2) identifying soil health indicators used by the farmers and comparing with literature;

(3) taking soil measurements (of indicators) with the help of farmers at the on-farm trials;

(4) discussing the soil measurement results and their connection to farmer observations.

The rationale behind the sequential step wise process is based on previous local soil health assessments applied in SSA (Mairura *et al.*, 2007; Prudat *et al.*, 2018). The four steps were defined and clarified in community meetings during the research design process in order to provide a clear replicable framework, embedded in both social (Newing, 2011) and soil science (Carter & Gregorich, 2007) literature, and able to cover multiple indicators of soil health.

Focus groups and semi-structured interviews were conducted to understand farmers' perspectives on soil health, the agro-ecological system and their decision-making (Newing, 2011). Focus groups were conducted in each community with both trial farmer group (6 farmers) and non-trial farmers (8–10 farmers). A total of 3 focus groups per community were organized. Guiding discussion topics (Appendix C.2) based on observations or indicators used for assessment of different management practices were provided to explore local soil health knowledge.

The semi-structured interviews followed the focus groups. Interviews enabled in-depth conversations on the indicators used for soil health assessment, and plant and soil outcomes from different management practices. They also supported exploring the diversity in farmers' approaches without the need for group consensus as often required in focus group discussions. The frequency count of indicators and outcomes based on interview results was used to map out the popularity of particular indicators and observations. The semi-structured interviews were conducted with 6 trial farmers in each community and a subsequent snowball methodology, with support from the extension officer, was used to select 12 non trial farmers in Mwansambo and 14 non trial farmers in Lemu. During the interviews, questions about currently used land management practices were asked to clarify the use of CA practices. In total 38 interviews were conducted and the guiding questions can be found in Appendix C.2.

The selection criteria for participants was based on engagement levels with the CA trials (Hermans et al., 2020b). Trial farmers have most experience with the impact of CA practices, as they directly implement the trials on their land and have direct engagement with the International Maize and Wheat Improvement Center (CIMMYT) and agricultural extension officers. Since the rationale of this study is to gain a broad perspective and understanding on the process and learning across knowledges, the non-trial farmers were selected to represent various age groups and to provide a gender balance in respondents.

Before the interviews and focus groups, written consent was obtained from participants and it was clarified that participation had no influence on any programme involvement and that responses will be anonymised. Ethical consent for this study was obtained from the University of Leeds and Lilongwe University of Agriculture and Natural Resources.

The data was firstly analysed on the frequency of mentioned impacts of CA practices on soil health and the indicators used for this assessment. Using the outcomes and indicators as themes, the qualitative data was explored for each theme to gain an in-depth understanding of the reasoning, observation and assessment (Saldaña, 2015).

3.2.3 Soil measurements

Based on discussions of soil health, the impact of CA practices and the soil health MDS (Table 3.1) a set of soil measurements were taken. Soil was sampled and analysed from both sites during February 2019 growing season. Soil measurements covered soil C, total N, nitrate/nitrite, ammonium, infiltration, moisture, structure, bulk density and maize yield. Farmers were involved in the field measurements of soil N, soil infiltration, moisture, soil structure and bulk density to ensure their awareness of measurement techniques and participation in sampling, ahead of two-way discussion of findings.

3.2.3.1 Soil carbon and nitrogen

Soil samples were collected from all treatment plots at two depths (0-5 cm and 5-10 cm) using an Edelman auger. For each treatment and depth, five soil sub-samples were taken and bulked into a composite sample for analysis. The sub-samples were taken in a Z pattern to get a bulked representation of the plot treatment and enable comparison to the other two treatments (Carter & Gregorich, 2007). From the bulked samples, 3 sub samples of 2 ml of moist soil per field were analysed within 24 hours for soil nitrate, nitrite and ammonium using a SKW500 Palintest© soil fertility kit (https://www.palintest.com/products/skw500-complete-soil-kit/). This involved extraction with 1M ammonium chloride and spectrophotometer reading *in situ* (Carter & Gregorich, 2007). Each final treatment value consisted of N=18 measurements. The remaining bulked samples were air-dried, crushed and passed through a 2 mm sieve, then ball-milled, before total carbon and nitrogen were determined through combustion in an elemental analyser (Elementar Vario Micro Cube) (McGeehan & Naylor, 1988). Each final measurement TC/TN per treatment per depth per community is the mean of 12 sub samples.

3.2.3.2 Soil infiltration & Moisture

Field infiltration measurements were taken with a minidisk tension infiltrometer (METER Group Inc., 2018) with the suction rate set to accommodate for the soil type and texture (Table 3.2), ranging from -0.5 (compact soil) to -6 cm (sandier soils) following the manufacturer's guide. Ten measurements were taken following a W-pattern in each replicate plot. Infiltration measurements were taken at intervals of 10 seconds and cumulative infiltration calculated by regressing infiltration measurements with time (Kirkham, 2014). Each final measurement per treatment per community is the mean of 30 measurements. *In situ* soil moisture readings were taken (25 per treatment per field) using a Delta soil moisture probe (https://www.delta-t.co.uk/product/ml3-kit/).

3.2.3.3 Soil structure stability index

The soil structural stability index (Pieri, 1992) was estimated based on soil organic carbon, clay and silt contents:

$$Soil\ structural\ stability\ index = \frac{1.72OC(wt.\%)}{(Clay + Silt)(wt.\%)} \times 100. \qquad 1$$

3.2.3.4 Bulk Density

Soil samples for bulk density determination were collected from three points in each treatment plot with a van Eijkelkamp sample ring (5 cm diameter x 5 cm length). The three points were selected around the centre of the field to avoid the border of the field and represent different ridges or maize planting lines. The samples were oven dried for 24 hours at 105°C and a bulk density value calculated:

$$Bulk\ Density\ (gcm^{-3}) = \frac{Mass\ of\ oven - dry\ soil}{Volume\ of\ soil} \qquad 2$$

Each final measurement per treatment per community is the mean of 18 samples.

3.2.3.5 Visual Evaluation of Soil Structure (VESS)

The assessment of soil structure for each treatment plot was conducted using the Visual Evaluation of Soil Structure (VESS) chart (Ball *et al.*, 2007). The VESS method uses an illustrated ranking table of soil structure. A structural quality (Sq) score ranging from 1 (good) to 5 (bad) is assigned based on the stability of the aggregates with use of reference photographs (Ball *et al.*, 2007; Mueller *et al.*, 2013).

3.2.3.6 Yield

The reported maize yield was based on 10 sub-samples of 7.5 m^2 per treatment for 2019, as described in Thierfelder et al. (2013). Weight of biomass and fresh cobs was recorded in field after harvest at physiological maturity. Four weeks after the harvest in end April for Lemu and May for Mwansambo, biomass, shelled grain and dry cobs were weighed and grain moisture was measured. Maize grain yield is based on the conversion of yield data at 12.5% moisture content to $kgha^{-1}$ (Thierfelder *et al.*, 2013).

3.2.3.7 Statistics

Normally distributed soil nitrogen, carbon, infiltration, bulk density, structural stability and yield data were subject to an analysis of variance (ANOVA) to test for differences between the CP and CA treatments (Fisher, 1992). The Tukey HSD post hoc test was used for mean separation (Tukey, 1949). Mean comparison and separation for the non-parametric data were tested using Kruskall-Wallis test and Dunn's test respectively (Dunn, 1961; Kruskal & Wallis, 1952). Statistical analysis was performed in SPSS version 23.0.0.2 (IBM Corp, 2015).

3.3 Results

3.3.1 Farmers' soil health indicators

Interviews demonstrated that farmers observe the impacts of CA on soil health in relation to each of the three main CA component practices (Table 3.3). Practices from the CA package were also used by non-trial farmers, such as rotation, or translated into an adapted practice, such as residue burying in ridges or planting on old ridges (Table 3.3). Trial farmers also adopted non-CA practices. Therefore, the results are discussed as responses from the total group (Table 3.3, Appendix C.3).

Enhanced additions of crop residues were strongly connected with increasing soil moisture, soil organic matter and higher soil fertility, making the soil 'soft again' through moisture retention and protecting it from the sun ("*Residues keep moisture and without residues the crop is exposed to sunlight on the flat*" Farmer 1). This perception was common amongst trial farmers (Table 3.3). Some concerns were raised in regard to negative effects on the growth of the next crop: when residues do not decompose well, residues lead to waterlogging in high rainfall seasons, and the attraction of crop pests. Some farmers suggested that the fertility added through residue retention is not good for groundnuts and leads to lower yields.

Table 3.3 Farmers' perception of the impact of CA practices on soil dynamics. n is the frequency in responses and the percentage is based on the number of responses for the group total.

Perception	**n**	**n Trial (%Total 12)**	**n Non -trial (%Total 26)**
Residues			
Residue retention improves soil fertility and adds organic material.	26	10 (83%)	16 (62%)
Residue retention improves retaining soil moisture.	23	6 (50%)	17 (65%)
Flat land only works with residues, because without residues the soil is exposed to the sun, dries, and becomes hard.	10	4 (33%)	6 (23%)
Residue retention attract organisms.	10	2 (17%)	8 (31%)
Many residues and high soil fertility is not good for groundnuts.	9	2 (17%)	7 (27%)
More residues means less weeding, but too little means herbicides are needed.	6	3 (25%)	3 (12%)
If decomposition is not good it does not add to soil fertility and negatively affects growth of the next crop.	6	3 (25%)	3 (12%)
Residues prevent soil erosion.	6	2 (17%)	4 (15%)
Too many residues on flat land will lead to water logging.	6	1 (8%)	5 (19%)
Residues make the ground soft.	5	5 (42%)	0 (0%)
During harvest residues are fresh and good for decomposition. If the residues and soil are dry they are not good anymore and do not decompose well.	4	1 (8%)	3 (12%)
Residues create too much heat.	3	0 (0%)	3 (12%)
Termites help to decompose residues.	2	1 (8%)	1 (4%)
Importing residues risks disease transfer.	1	0 (0%)	1 (4%)
Rotation			
Rotation is good because legume leaves decompose and improve fertility.	10	5 (42%)	5 (19%)
Rotation decreases diseases because diseases do not survive if crops change.	6	2 (17%)	4 (15%)
Rotation is good because crops have specific nutrients and rotating means these can be replenished.	2	0 (0%)	2 (8%)
Ridge making			
No till means the soil is not shaken by the hoes and the soil cannot wash away, so old ridges (banking only) or no till is better.	15	4 (33%)	11 (42%)

Ridges can aerate the soil and make it soft again, so seeds can get nutrients easily.	10	2 (17%)	8 (31%)
Ridges lose moisture quickly.	5	1 (8%)	4 (15%)
Ridge making is good because crop is above water table.	5	0 (0%)	5 (19%)
Ridges or furrows help with conserving water.	5	0 (0%)	5 (19%)
On the flat the water infiltrates, but with ridges the water flows.	4	1 (8%)	3 (12%)
Ridges make water infiltrate quickly in the soil and collect water.	3	0 (0%)	3 (12%)
New ridges will redistribute the soil fertility	2	0 (0%)	2 (8%)
In ridges it takes longer for residues to decompose because there is less moisture.	2	1 (8%)	1 (4%)
On ridges groundnut cannot grow big because it is limited by the ridge sides.	2	0 (0%)	2 (8%)
Ridges help to decompose residues quicker.	1	1 (8%)	0 (0%)

Farmers observed that new ridges are often washed away when the wet season starts. Despite the negative perception on soil erosion, ridges are perceived to aerate the soil and making it softer, so seeds can access nutrients easily ("*I make ridges so the soil can be soft again*" Farmer 4). Furthermore, the perceived benefits of no-till are highly dependent on residue quantity because without residues the soil is exposed to the sun and becomes dry and hard.

Rotation or intercropping with legumes was also perceived as useful because of the addition of "*something good*", described by some as "*adding salt"* (i.e. akin to enhancing the flavour of food) to the soil. In particular, the decomposition of legume leaves improves soil fertility and replenishes the soil nutrients ("*Pigeon pea leaves, when they fall they improve soil fertility*" Farmer 7). The collected statements on how CA might affect soil health, demonstrated that farmers perceive the CA practices to lead to a soil or plant outcome. Further discussion on these outcomes enabled us to collate a list of soil and plant indicators used by farmers to assess soil health (Figure 3.2, Table 3.4, Appendix C.3).

All indicators are based on visual or touch senses and are mostly described in relative terms, for example yellow or green plant, hard or soft soil, and fast or slow growth. The key indicators used by at least 50% of interviewed farmers were crop yield (63%) and soil consistency (50%) (Appendix C.3). In addition to crop yield, the other crop characteristics mentioned by 50% of CA trial farmers was crop colouration whereas the non-trial farmers (50%) emphasised crop vigour.

The indicators can be linked to the understanding of processes listed in Table 3.3. For example, soft or hard was used to describe the impact of ridges and residues (e.g., "*without residues the* *soil is exposed to the sun and becomes hard"*, "*ridges aerate the soil and make it soft again"*). Moisture was referred to in various statements about ridges and residues, which can keep or lose moisture (e.g., "*residues improve retaining moisture"*, "*ridges lose moisture quickly"*). Erosion is also a reoccurring outcome used to indicate the success of an agricultural practice, in particular ridge making and residue retention. Although yield was not explicitly mentioned as an outcome based on the identified processes in Table 3.3, it is viewed as an overall proxy of soil health.

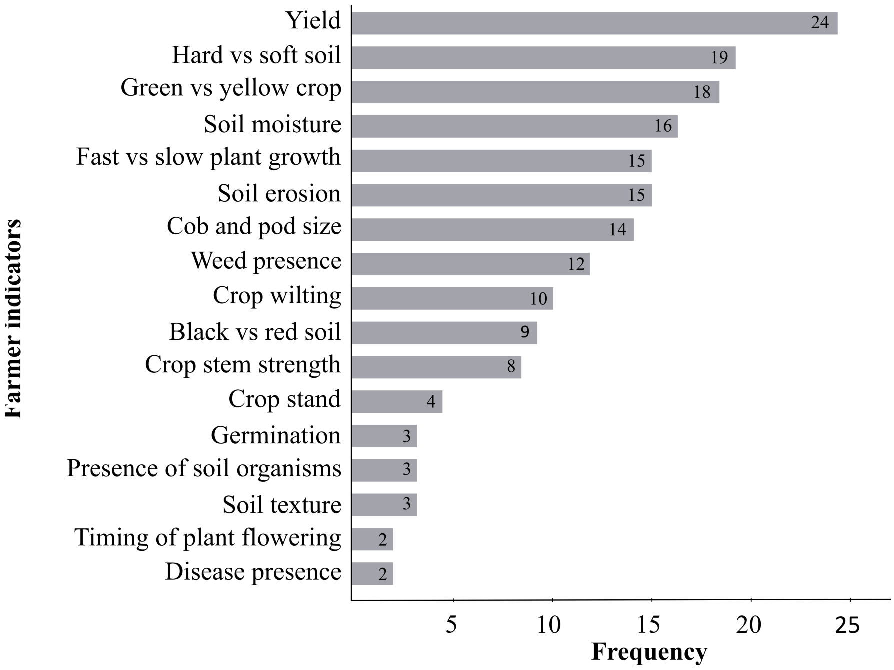

Figure 3.2 Frequency table of the indicators used by farmers to assess soil health. The frequency is the number of interviews in which this indicator was explicitly mentioned by farmers. A breakdown of frequency for trial and non-trial farmers can be found in Appendix C.3

Table 3.4 Indicators of good soil health as perceived by farmers.

Indicators of good soil health	
Soft soil	No erosion
High Yield	Strong plant
Green Crop	Black soil
Fast plant growth	High germination
Large pod and cob	High moisture

3.3.2 Quantitative soil health indicators selection

Soil properties that correspond with farmers' indicators of soil health and could be measured were total C, total N, available N (as ammonium, nitrite and nitrate), infiltration, moisture, bulk density and soil structure (Table 3.5). An example of the connection is the green vs yellow plant: according to farmers, a greener plant is perceived as 'good', whereas a yellow plant is perceived as 'bad'. It was largely unknown by the farmers, however, that the yellow colour is caused by a shortage of nutrients, in particular N, which can be quantitatively measured. Further, the colour of the dark soil and high moisture identified by farmers as 'good' provides a connection to the MDS parameter of organic matter (soil C) and water holding capacity, respectively (Gupta *et al.*, 2008). The frequent noting of erosion as an indicator can be translated to measurement of infiltration, which can indicate erosion potential and soil structure (Table 3.1).

Table 3.5 Soil health indicators selected for comparing conservation agriculture with the conventional treatment. The soil health measurements were selected based on literature, whereas the farmer soil health indicators show what farmers look at when comparing fields.

Farmer soil health indicators		Soil health measurements	
Hard vs soft soil - D	SOIL	Total Carbon - C	SOIL
Soil moisture - M		Total Nitrogen - N	
Soil erosion- E		Ammonium - N	
Black vs red soil -C		Nitrate & Nitrite - N	
Presence of soil organisms - B		Infiltration & Moisture – M E	
Soil texture – C		Soil Structure Stability Index – DE	
Yield - C E M D N B	PLANT	Bulk Density - D	
Fast vs slow plant growth – C E M D N B		Visual Evaluation of Soil Structure (VESS) – DE	
Green vs yellow crop - N		Yield – C E M D N B	PLANT
Cob and pod size – C E M D N B			
Crop wilting – C E M D N B			
Crop stem strength- C E M D N B			
Crop stand- C E M D N B			
Timing of plant flowering- C E M D N B			
Germination – C E M D N B			
Weed presence	OTHER		
Disease presence			

B - Soil organisms were excluded from measurements because literature review showed general consensus on CA leading to higher biological activity (Thierfelder *et al.*, 2015b). *D- indicators and measurements related to soil density, M - indicators and measurements related to soil moisture, E - indicators and measurements related to soil erosion (and connected soil structure), C- indicators and measurements related to soil carbon, N - indicators and measurements related to soil nitrogen.*

3.3.3 Quantitative soil health measurements

3.3.3.1 Total carbon, total nitrogen, and available nitrogen

CAML and CAM systems were not significantly different from the CP system in total soil C, despite 15% and 5% higher total C contents, respectively (Figure 3.3, Appendix C.4). Total N was higher in the CAM (0.98 gkg^{-1}) and CAML (1.19 gkg $^{-1}$) systems than in the CP system (0.90 gkg $^{-1}$) with this being statistically significant only at the 0–5 cm depth ($p < 0.05$) (Figure 3.3, Appendix C.4). The CP system had a significantly ($p < 0.05$) higher nitrite and nitrate value (200.7 mgkg $^{-1}$) in Mwansambo than the CA systems (CAM 171.9 mgkg $^{-1}$, CAML 103.3 mgkg $^{-1}$) with a difference of 14% and 49%, respectively (Figure 3.4, Appendix C.4). There were significantly higher values of soil ammonium in the CP systems in Lemu (76.0 mgkg $^{-1}$) than CA systems (CAM49.4 mgkg^{-1}, CAML51.7 mgkg^{-1}) (Figure 3.4). Ammonium in the CP treatment was 32–35% higher compared to CA treatments. The ammonium values in Mwansambo were mostly outside the range of the spectrometer and the only detectable values were for some of the CA fields.

The change in soil C concentrations in the on-farm trial plots between 2011, based on Cheesman et al. (2016), and 2019 was not significant (Appendix Table C.5).

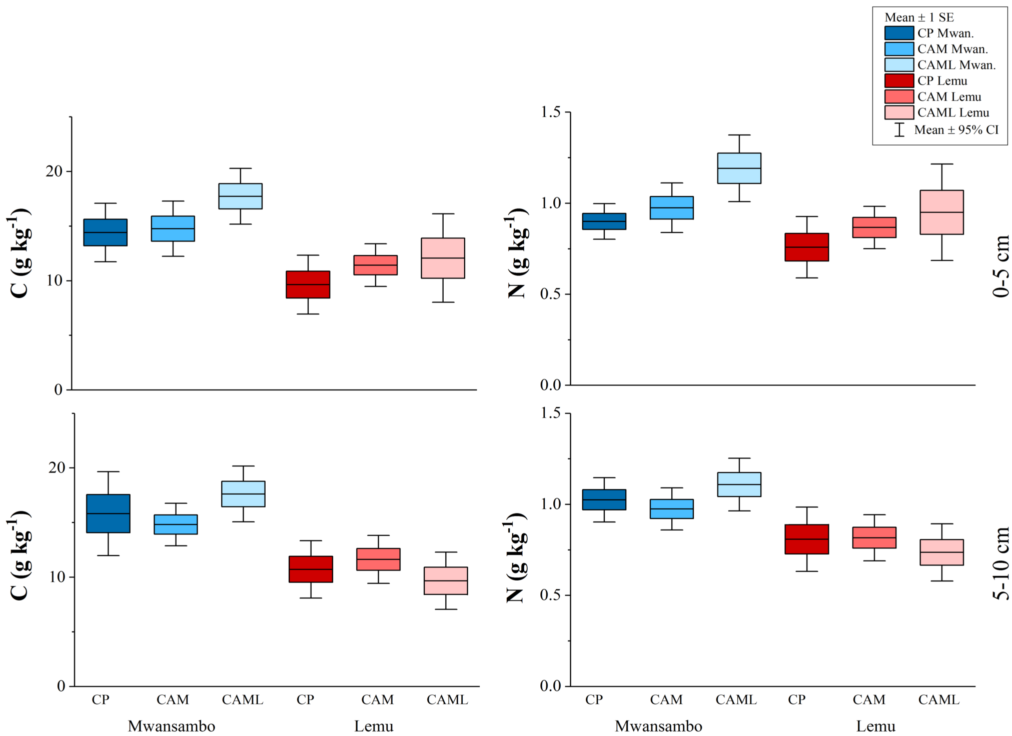

Figure 3.3 Total Carbon (C) and Total Nitrogen (N) data for 0–5 cm and 5–10 cm depth showing mean ± 1 standard error (SE) (whiskers show 95% confidence interval (CI)). Lemu data is represented in the red colours and Mwansambo (Mwan.) in the blue colours. Dark red and blue represent measurement from maize in conventional practice (CP), middle colour represents CA with maize only (CAM) and lightest colour represents CA with maize-legume intercropping (CAML).

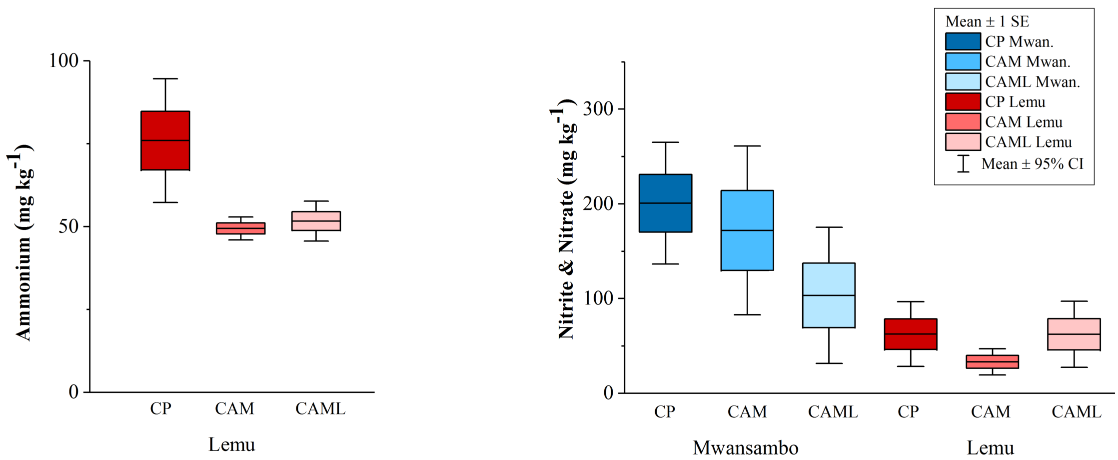

Figure 3.4 Ammonium and nitrate/nitrite data for 5–10 cm depth showing mean ± 1 standard error (SE) (whiskers show 95% confidence interval (CI)). Lemu data is represented in the red colours and Mwansambo (Mwan.) in the blue colours. Dark red and blue represent measurement from maize in conventional practice (CP), middle colour represents CA with maize only (CAM) and lightest colour represents CA with maize-legume intercropping (CAML).

3.3.3.2 Infiltration, moisture and soil structure

Significant impacts of land management on the rate of water infiltration was only observed in Lemu where CAML and CAM had an infiltration rate of 0.15 cms^{-1} and CP 0.09 cms^{-1}, respectively (Figure 3.5, Appendix C.6). Comparing CP to the CA treatments, moisture readings were between 7.54% and 38.15% lower for CP in Mwansambo and 1.57%–47.39% lower for CP in Lemu.

Soil structural stability index was significantly greater in the CAML and CAM treatments than the CP treatment when the data for the two communities were combined (Figure 3.6, Appendix C.6). Bulk density measurements for 0–5 cm and 5–10 cm in both communities did not differ significantly ($p < 0.05$) (Appendix C.6).

With the help of soil quality scoring in the VESS exercise, the structure of the soils in the CAML and CAM was judged to be more stable than for CP treatments. Farmers also assessed that CAML and CAM treatments had softer and more easily breakable aggregates than those in CP treatments.

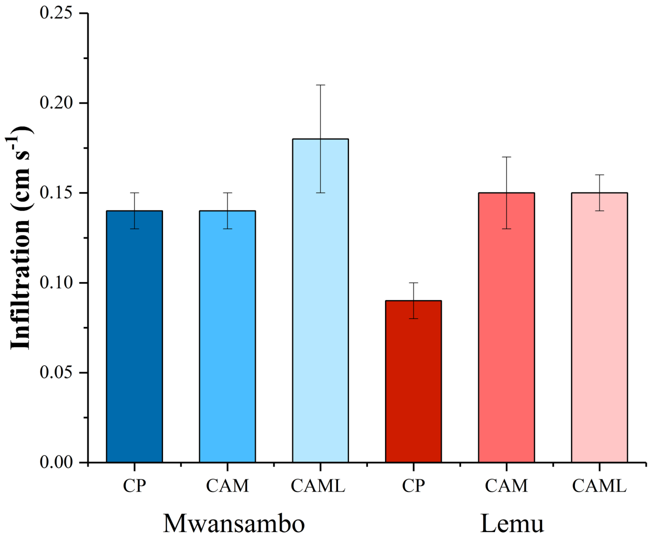

Figure 3.5 Infiltration data for Mwansambo (blue) and Lemu (red). Bars shows mean with standard error lines. Dark colour represents conventional treatment (CP), middle colour represents conservation agriculture with maize only (CAM) and lightest colour represents conservation agriculture with legume intercropping (CAML).

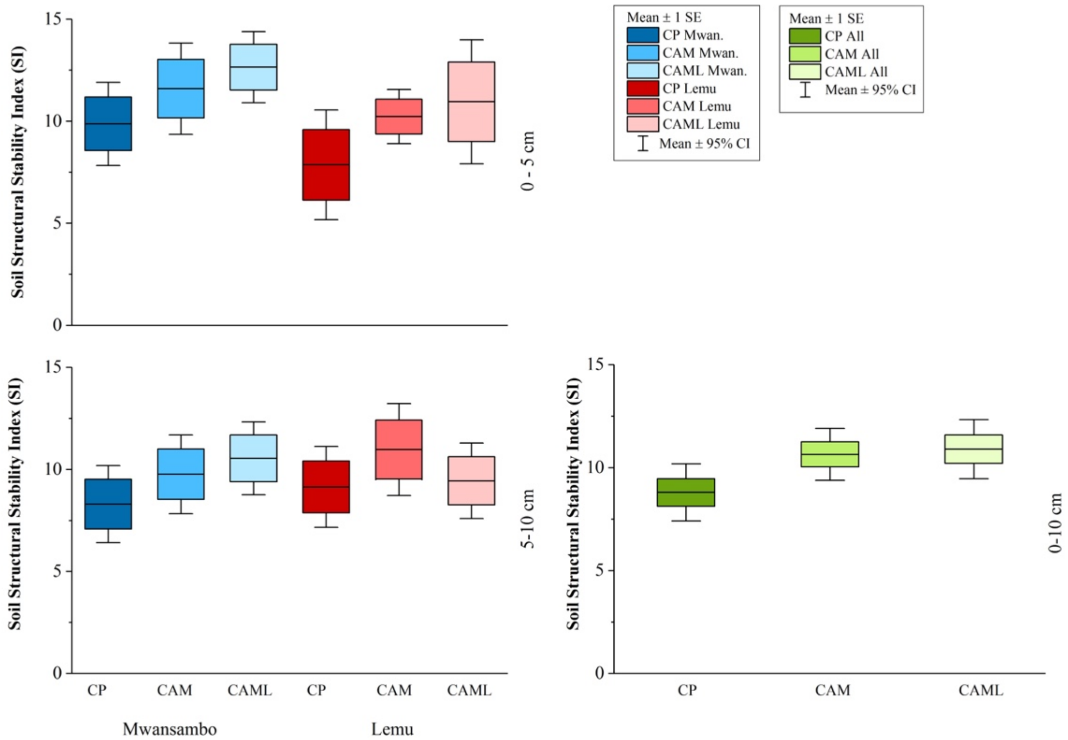

Figure 3.6 Soil structural stability index for Lemu (red) and Mwansambo (blue). Dark colour represents conventional treatment (CP), middle colour represents conservation agriculture with maize only (CAM) and lightest colour represents conservation agriculture with legume intercropping (CAML). Green colour shows the results for the data of the two communities combined.

3.3.3.3 Yield

Grain yield was significantly higher in the CA systems in Mwansambo, with CP 3225 $kgha^{-1}$, CAML 5067 $kgha^{-1}$ and CAM 5160 $kgha^{-1}$ ($p < 0.05$) (Appendix C.7). For Lemu, there was no significant difference ($p < 0.05$) (Appendix C.7), although CAML showed higher grain yields (3454 $kgha^{-1}$) compared to CP (2886 $kgha^{-1}$) and CAM (2872 $kgha^{-1}$).

3.4 Discussion

3.4.1 Soil health indicators

3.4.1.1 Carbon & nitrogen

The impacts of CA practices on soil C remains contested with different sites producing contrasting results, in particular between controlled research stations and farmer managed on farm trials. In our study, farmers observed that crop residue retention makes soils dark, soft, increases soil texture diversity and improves plant performance, which suggests that the practice of residue retention improves soil fertility and soil organic matter. The associated measurement of total C showed that C contents in the CA systems was not statistically significant due to high variance.

The quantity and quality of residues significantly impacts their decomposition rate and plays an important role in controlling soil C contents (Luo *et al.*, 2016). Additionally, rainfall during the dry season can speed up decomposition by microbes. Farmers mentioned that ridge making increases nutrient release and distributes soil fertility. This combination of positive attributes of mulching and ridge making has led to farmers incorporating residues in ridges. The aeration of soil during tilling incorporates residues and air in the soil, where there are many decomposing micro-organisms (Bot & Benites, 2005; Walters *et al.*, 1992). The practice of incorporating residues and oxygen in ridges speeds up the short term decomposition and decreases long term accumulation of organic matter in the soil (Bot & Benites, 2005; Walters *et al.*, 1992).

The role of legumes in intercropping or rotation systems received positive evaluations by farmers. They observed that legume rotation or intercropping improves soil fertility through replenishing nutrients so the next crop growth is ‘good’. They indicated that the crop colour being increasingly green as opposed to yellow showed this improvement, which can be connected to improved nitrogen levels (Snowball & Robson, 1991). In previous studies, total N was higher in CA treatments compared to conventional practices after 2 and 5 years (Mloza-Banda *et al.*, 2016, 2014).

The results of our study show that only the CA treatments with legume intercrop significantly increased total soil N contents, which was confirmed by farmers’ observations on the impact of crop diversification. This is expected as legumes are known to fix atmospheric N and Myaka et al. (2006) had reported that maize-pigeon pea intercrop can contribute up to 60 kg N ha^{-1}. The high quality of legume residues may reduce the C:N ratios of CAML thereby preventing temporary N immobilization by the soil microbial community (Adu-Gyamfi *et al.*, 2007). The forms of inorganic N species available to crops were significantly higher in the CP than the CA systems. According to the farmers, the practices of ridge-making aerates the soil and redistributes soil nutrients. The higher available N levels in CP support this farmer perception. However, the overall yield results show higher grain yields in CA systems.

3.4.1.2 Infiltration, moisture & structure

This study showed that after 10–12 years of CA, there was significant improvement in moisture and infiltration, particularly at Lemu with sandy soils. The impact of ridge-making on infiltration received both negative and positive observations. Our soils data did not show a difference in bulk density and demonstrated higher infiltration and yield under CA. This suggests that there may be discrepancies between farmer observations and soil measurements on the outcomes of ridge-making. Previous studies have shown that besides residue retention and higher associated biological activity leading to higher infiltration and that no-till practices also lead to changes in pore size distribution which improves infiltration (Bescansa *et al.*, 2006; Thierfelder & Wall, 2009).

Farmers' observations based on the soil structure exercise showed that soils under CA are softer, better structured, stable and have more easily breakable aggregates compared to CP. Farmers also commented that soil erosion decreased due to residue protection and the soil not being disturbed with a hoe. Marginal improvements in soil structural stability index have been reported in previous studies of Malawian on-farm trials after 4–5 years of CA practice (Mloza-Banda *et al.*, 2016, 2014). Improvement in soil structural stability index was found after 10–12 years of CA at on-farm trials, which support the farmer observations and yield outcomes.

3.4.2 Integrated approach for soil health assessment

In this paper we have presented a stepwise framework for the integrated field assessment of soil health in CA systems, enabling the integration of local and scientific knowledge sources. These steps involved (1) discussing CA's impact on soil health with farmers; (2) identifying farmer soil health indicators and comparing these with literature, (3) taking soil measurements of the indicators with the help of farmers at the on-farm trials; (4) discussing the soil measurements results and their connection to farmer observations. It is important to reiterate these steps in a learning process and assume an equal importance of both knowledges. This process can be applied across contexts to support a more comprehensive and robust understanding of dynamic and complex agricultural systems, including assumptions and ambiguities (Mairura *et al.*, 2007; Prudat *et al.*, 2018; Raymond *et al.*, 2010). Our findings show that there is value in the broader application and institutionalisation of such integrated learning and assessment processes, to enable technology adaptation to context and understand the role of soil health within farmer decision making. Whilst caution is required against taking context-specific findings from individual applications of such assessments and generalizing or scaling those findings across space and time, our insights do show that the process of an integrated approach is valuable and can be used in other contexts.

Soil health is one component in the complex decision-making process of agricultural practice adoption (Andersson & D'Souza, 2014). Other socio-economic factors such as labour, resources and social acceptability and dynamics also play an important role within this multifaceted decision-making (Hermans et al., 2020b). CA is however, promoted for its potential to improve soil health and to increase or sustain yield in the long-term. It is important to understand if farmers experience this improvement, or how they view other related benefits in terms of household labour demands.

The enrichment in knowledge on soil health through the integrated approach has shown that certain locally-used indicators are consistent with conventional soil health indicators used in the scientific literature. The process showed that defining soil health from a farmer perspective provided a broader set of soil health indicators, that were subject to defining a 'good' or 'bad' field (e.g., plant and disease indicators). There is particular value in understanding the link between processes and outcomes as described in soil literature and in relation to farmers' observations, which enables the comparison between local knowledge and scientific indices. The improvement of the connection to farmers' experience can subsequently enhance adaptation and uptake of CA and sustainable land management practices.

The integrated approach also improved the understanding of farmers' land management decision-making, and the role of soil health knowledge in this process. The local experience of process and outcomes has resulted in the inclusion of residues in the conventional practice of ridge making. This adaptation challenges the comparison of soil C in conventional and CA systems. Whereas our measurements and farmer indicators show a structural improvement under CA practices such as minimum tillage, the integrated knowledge and methods process reveals mixed observations and understanding on the impact of ridge-making on the soil. CA's positive impact on soil erosion was clear, but simultaneously there is an association of ridges positively affecting soil fertility and aeration. These outcomes are dependent on field context, for example, hillsides are more susceptible to erosion than flat land. The trade-off has led to farmers' adoption of planting on old ridges or banking after the rains, in which case the soil is still mixed, aerated and softened, but erosion is reduced and the soil does not become hard. The integration, comparison and exploration of local and scientific knowledge has enriched our understanding of CA's impact on soil health and farmer evaluation, and soil health prioritization. Both the local and scientific forms of knowledge add to the overall understanding of CA performance and the drivers or processes explaining the outcome ('why does it work here?').

The process of learning across local and scientific knowledge does have limitations. One main concern is that not all local indicators and scientific soil health literature map onto one another. Some of the local indicators do not capture the long-term dynamics or soil health sensitivity. The decision, for example, to incorporate residues into the ridges because of the knowledge on residue benefits does not consider the potentially long-term degrading effect on soil C due to faster decomposition. The indicators used by farmers cover a wider set of parameters including various proxy indicators (e.g., yield, crop strength, cob/pod size, growth speed), but they do not reveal specific processes. The translation of indicators to measurements also creates challenges due to the different set of words in the local language for describing soil dynamics (e.g., 'adding salt'), which can influence the interpretation of recorded responses.

Some measurements, such as C and N require analysis in a laboratory and need to be taken out of the community context. This makes it important to include iterative cycles of assessment, interpretation and discussion without assuming one knowledge is more important than another, as part of mixed methods or participatory monitoring approaches. Two-way feedback with farmers is still frequently missing, but is important to cross check outcomes and consequent decision-making. There are various forms of participatory research and on-farm trials, such as mother-baby trial systems (Biggs, 1989; Snapp & Silim, 2002) or Participatory Action Research (PAR) (Ernesto Méndez *et al.*, 2017). In this study, the on-farm trial design was controlled by researchers, and farmers maintained the trial with assistance and instruction from the extension officer. Farmers participated in sampling on trials and knowledge exchange through the interpretation of soil measurements, whilst the trial set-up has provided the internal validity and robustness needed in agronomic soil research. This addresses some of the concerns about a trade-off between scientific rigour and participation due to the integration of local and scientific knowledge (Reed, 2008). However, this also limits the level of participation, but provides a starting point for further development and discussion.

Previous work conducted in these communities has focused on knowledge transfer which creates a mix of 'old' and 'new' knowledge dependent on information and knowledge access of the farmers. Combining different knowledges requires the researcher's own assumptions to be recognized and addressed in regard to gender differences in knowledge, assumptions in ranking knowledge, the framing of 'scientific objectivity', the presence of a single 'coherent' or individual knowledge, and networks of knowledge (Baker *et al.*, 2019; Ramisch, 2012). The trial farmers have more extensive agricultural experience with CA practices, and information access compared to other farmers. Through involvement of non-trial farmers this was balanced, but this could lead to respondents' bias in terms of explaining the processes and outcomes. The improved understanding of farmer decision-making based on the perception of the outcomes of CA can enhance more widespread CA adoption and local adaptations.

3.5 Conclusion

In this study an integrated mixed methods and knowledge assessment approach was developed and implemented to evaluate soil health impacts of Conservation Agriculture (CA). A stepwise framework enabling learning across local and scientific knowledge sources is presented: (1) discussing soil health impact with farmers; (2) identifying and comparing farmer and literature soil health indicators, (3) taking soil measurements (of indicators) with the help of farmers; (4) discussing soil measurements results and farmer observations. The learning across knowledges requires iteration of the various steps to avoid knowledge ranking and to reflect on assumptions.

The translation of farmer-derived indicators to soil measurements showed that some indicators link directly to key conventional soil health indicators such as soil C, N, structure, soil moisture and infiltration. Soil health measurements and farmer observation showed that CA mainly leads to significant improvement in infiltration, soil structure and yield. In the conventional practice, higher exchangeable ammonium, nitrate/nitrite values were recorded, which corresponded with farmers perception of ridges redistributing nutrients. The combination of farmer observation and soil measurements highlights some discrepancies, notably in relation to ridge-making. The perceived benefits of residues (e.g., in terms of C) and ridges as redistribution of nutrients has led to the popular practice of burying residues in ridges. Such discrepancies can identify the reasons why farmers make certain contextualised land management decisions such as continuing making laborious ridges.

The development and implementation of an integrated approach to understand CA's impact on soil health is valuable in providing a wider evidence base and contextualizing soil health data. Whereas the aim is not to generalize or upscale local knowledge in itself, the learning process can be generalized to facilitate technology downscaling (e.g., CA adaptation and adoption) into a local context and to understand the role of soil health within farmer decision-making. The co-generation of knowledge on soil health has the potential to increase the knowledge engagement, ownership and trust relations, thereby enhancing the adaptation of CA and sustainable land management to local context.

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Credit author statement

Conceptualization: TH, AD, SW, CP, CT; Methodology: TH, AD, CL, SW, SE, CT; Formal analysis: TH, SW, SE; Investigation: TH, SE; Resources: TH, AD, CT; Writing – original draft: TH; Writing – review & editing: AD, CL, SW, SE, CT; Visualization: TH

References

Adu-Gyamfi JJ, Myaka FM, Sakala WD, Odgaard R, Vesterager JM, Høgh-Jensen H. 2007. Biological nitrogen fixation and nitrogen and phosphorus budgets in farmer-managed intercrops of maize-pigeonpea in semi-arid southern and eastern Africa. *Plant and Soil* 295: 127–136. DOI: 10.1007/s11104-007-9270-0

Andersson JA, D'Souza S. 2014. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment* 187: 116–132. DOI: 10.1016/j.agee.2013.08.008

Arshad MA, Coen GM. 1992. Characterization of soil quality: Physical and chemical criteria. American *Journal of Alternative Agriculture* 7: 25–31. DOI: 10.1017/S0889189300004410

Baker K, Eichhorn MP, Griffiths M. 2019. Decolonizing field ecology. *Biotropica* 51: 288–292. DOI: 10.1111/btp.12663

Ball BC, Batey T, Munkholm LJ. 2007. Field assessment of soil structural quality - a development of the Peerdklamp test. *Soil Use and Management* 23: 329–337. DOI: 10.1111/j.1473-2743.2007.00102.x

Baudron F, Tittonell P, Corbeels M, Letourmy P, Giller KE. 2011. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. *Field Crops Research* 132: 117–128. DOI: 10.1016/j.fcr.2011.09.008

Bescansa P, Imaz MJ, Virto I, Enrique A, Hoogmoed WB. 2006. Soil water retention as affected by tillage and residue management in semiarid Spain. *Soil and Tillage Research* 87: 19–27. DOI: 10.1016/j.still.2005.02.028

Biggs SD. 1989. *Resource-Poor Farmer Participation in Research: A Synthesis of Experiences from Nine National Agricultural Research Systems*. The Hague, Netherlands

Bot A, Benites J. 2005. *The importance of soil organic matter. FAO SOILS BULLETIN.* Food and Agriculture Organization of the United Nations: Rome

Bünemann EK, Bongiorno G, Bai Z, Creamer RE, De Deyn G, de Goede R, Fleskens L, Geissen V, Kuyper TW, Mäder P, Pulleman M, Sukkel W, van Groenigen JW, Brussaard L. 2018. Soil quality – A critical review. *Soil Biology and Biochemistry* 120: 105–125. DOI: 10.1016/j.soilbio.2018.01.030

Carter MR, Gregorich EG. 2007. *Soil Sampling and Methods of Analysis 2nd Edition. Soil Sampling and Methods of Analysis.* CRC Press: Canada. DOI: 10.1201/9781420005271

Carter MR, Gregorich EG, Anderson JW, Doran JW, Janzen HH, Pierce FJ. 1997. Concepts of soil quality and their significance. In: Gregorich EG and Carter MR (eds) *Soil Quality for Crop Production and Ecosystem Health.* Elsevier: Amsterdam, Netherlands, 1–19

Cheesman S, Thierfelder C, Eash NS, Kassie GT, Frossard E. 2016. Soil carbon stocks in conservation agriculture systems of Southern Africa. *Soil and Tillage Research* 156: 99–109. DOI: 10.1016/j.still.2015.09.018

Dunn OJ. 1961. Multiple Comparisons among Means. *Journal of the American Statistical Association* 56: 52–64. DOI: 10.1080/01621459.1961.10482090

Ernesto Méndez V, Caswell M, Gliessman SR, Cohen R. 2017. Integrating agroecology and participatory action research (PAR): Lessons from Central America. *Sustainability* 9: 1–19. DOI: 10.3390/su9050705

Eze S, Dougill AJ, Banwart SA, Hermans TDG, Ligowe IS, Thierfelder C. 2020. Impacts of conservation agriculture on soil structure and hydraulic properties of Malawian agricultural systems. *Soil and Tillage Research* 201: 104639. DOI: 10.1016/j.still.2020.104639

FAO. 2015. *Conservation Agriculture. http://www.fao.org/conservation-agriculture/en/*

Fisher RA. 1992. Statistical Methods for Research Workers. In: Kotz S and Johnson NL (eds) *Breakthrough in Statistics. Springer Series in Statistics (Perspectives in Statistics).* Springer: New York, NY. DOI: https://doi.org/10.1007/978-1-4612-4380-9_6

Giller KE, Corbeels M, Nyamangara J, Triomphe B, Affholder F, Scopel E, Tittonell P. 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. *Field Crops Research* 124: 468–472. DOI: 10.1016/j.fcr.2011.04.010

Giller KE, Witter E, Corbeels M, Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* 114: 23–34. DOI: 10.1016/j.fcr.2009.06.017

Govaerts B, Sayre KD, Deckers J. 2006. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. *Soil and Tillage Research* 87: 163–174. DOI: 10.1016/j.still.2005.03.005

Gregorich EG, Carter MR, Angers DA, Monreall CM, Ellerta BH. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian *Journal of Soil Sciene* 74: 367–385. DOI: https://doi.org/10.4141/cjss94-051

Gupta RK, Abrol IP, Finkl CW, Kirkham MB, Arbestain MC, Macías F, Chesworth W, Germida JJ, Loeppert RH, Cook MG. 2008. Soil color. In: Chesworth W (ed) *Encyclopedia of Soil Science. Encyclopedia of Earth Sciences Series*. Springer: Dordrecht, 641–643. DOI: 10.1007/978-1-4020-3995-9_534

Hermans TDG, Whitfield S, Dougill AJ, Thierfelder C. 2020a. Bridging the disciplinary gap in conservation agriculture research, in Malawi. A review. *Agronomy for Sustainable Development* 40: 3. DOI: 10.1007/s13593-020-0608-9

Hermans TDG, Whitfield S, Dougill AJ, Thierfelder C. 2020b. Why we should rethink 'adoption' in agricultural innovation: Empirical insights from Malawi. *Land Degradation and Development* 1–12. DOI: 10.1002/ldr.3833

IBM Corp. 2015. IBM SPSS Statistics for Windows, Version 23.0. IBM Corp: Armonk, NY

Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Schuman GE. 1997. Soil Quality: A Concept, Definition, and Framework for Evaluation (A Guest Editorial). *Soil Science Society of America Journal* 61: 4. DOI: 10.2136/sssaj1997.03615995006100010001x

Kassam A, Friedrich T, Derpsch R. 2019. Global spread of Conservation Agriculture. International *Journal of Environmental Studies* 76: 29–51. DOI: 10.1080/00207233.2018.1494927

Kirkham MB. 2014. *Principles of soil and plant water relations, 2nd Edition.* Academic Press,. DOI: 10.1016/C2013-0-12871-1

Kruskal WH, Wallis WA. 1952. Use of Ranks in One-Criterion Variance Analysis. *Journal of the American Statistical Association* 47: 583–621. DOI: 10.1080/01621459.1952.10483441

Laishram J, Saxena KG, Maikhuri RK, Rao KS. 2012. Soil Quality and Soil Health : A Review. *International Journal of Ecology and Environmental Sciences* 38: 19–37

Ligowe IS, Cleoups Nalivata P, Njoloma J, Makumba W, Thierfelder C. 2017. Medium-term effects of conservation agriculture on soil quality. *African Journal of Agricultural Research* 12: 2412–2420. DOI: 10.5897/AJAR2016.11092

Luo Z, Wang E, Sun OJ. 2016. A meta-analysis of the temporal dynamics of priming soil carbon decomposition by fresh carbon inputs across ecosystems. *Soil Biology and Biochemistry* 101: 96–103. DOI: 10.1016/j.soilbio.2016.07.011

Mairura FS, Mugendi DN, Mwanje JI, Ramisch JJ, Mbugua PK, Chianu JN. 2007. Integrating scientific and farmers' evaluation of soil quality indicators in Central Kenya. *Geoderma* 139: 134–143. DOI: 10.1016/j.geoderma.2007.01.019

McGeehan SL, Naylor D V. 1988. Automated instrumental analysis of carbon and nitrogen in plant and soil samples. *Communications in Soil Science and Plant Analysis* 19: 493–505. DOI: 10.1080/00103628809367953

METER Group Inc. 2018. Mini Disk Infiltrometer. Mini Disk Infiltrometer. METER Group Inc.: Pullman, WA, USA, 1–21

Mloza-Banda HR, Makwiza CN, Mloza-Banda ML. 2016. Soil properties after conversion to conservation agriculture from ridge tillage in Southern Malawi. *Journal of Arid Environments* 127: 7–16. DOI: 10.1016/j.jaridenv.2015.11.001

Mloza-Banda ML, Cornelis WM, Mloza-Banda HR, Makwiza CN, Verbist K. 2014. Soil properties after change to conservation agriculture from ridge tillage in sandy clay loams of mid-altitude Central Malawi. *Soil Use and Management* 30: 569–578. DOI: 10.1111/sum.12139

Mueller L, Shepherd G, Schindler U, Ball BC, Munkholm LJ, Hennings V, Smolentseva E, Rukhovic O, Lukin S, Hu C. 2013. Evaluation of soil structure in the framework of an overall soil quality rating. *Soil and Tillage Research* 127: 74–84. DOI: 10.1016/J.STILL.2012.03.002

Newing H. 2011. *Conducting Research in Conservation. A social science perspective*. Routledge: Abingdon, Oxon

Ngwira AR, Sleutel S, de Neve S. 2012a. Soil carbon dynamics as influenced by tillage and crop residue management in loamy sand and sandy loam soils under smallholder farmers' conditions in Malawi. *Nutrient Cycling in Agroecosystems* 92: 315–328. DOI: 10.1007/s10705-012-9492-2

Ngwira AR, Thierfelder C, Lambert DM. 2012b. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems* 28: 350–363. DOI: 10.1017/S1742170512000257

Oppenheimer M, Campos M, Warren R, Birkmann J, Luber G, O'Neill B, Takahashi K. 2014. Emergent risks and key vulnerabilities. In: Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR and White LL (eds) *Climate Change 2014. Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate*

Change. Cambridge University Press: Cambridge, United Kingdom and New York, NY, USA., 1039–1099

Parisi V, Menta C, Gardi C, Jacomini C, Mozzanica E. 2005. Microarthropod communities as a tool to assess soil quality and biodiversity: A new approach in Italy. *Agriculture, Ecosystems and Environment* 105: 323–333. DOI: 10.1016/j.agee.2004.02.002

Pieri CJMG. 1992. *Fertility of Soils : a Future for Farming in the West African Savannah*. Springer Berlin Heidelberg

Powlson DS, Stirling CM, Thierfelder C, White RP, Jat ML. 2016. Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agriculture, Ecosystems and Environment* 220: 164–174. DOI: 10.1016/j.agee.2016.01.005

Prudat B, Bloemertz L, Kuhn NJ. 2018. Local soil quality assessment of north-central Namibia: Integrating farmers' and technical knowledge. *Soil* 4: 47–62. DOI: 10.5194/soil-4-47-2018

Ramisch JJ. 2012. 'This Field Is Our Church': The social and agronomic challenges of knowledge generation in a participatory soil fertility management project. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World.* Routledge: Abingdon, Oxon, 146–174. DOI: 10.4324/9780203125434

Raymond CM, Fazey I, Reed MS, Stringer LC, Robinson GM, Evely AC. 2010. Integrating local and scientific knowledge for environmental management. *Journal of Environmental Management* 91: 1766–1777. DOI: 10.1016/j.jenvman.2010.03.023

Reed MS. 2008. Stakeholder participation for environmental management: A literature review. *Biological Conservation*, 2417–2431. DOI: 10.1016/j.biocon.2008.07.014

Saldaña J. 2015. *The coding manual for qualitative researchers.* SAGE: Los Angeles

Singer MJ, Ewing S. 2000. Soil Quality. In: Sumner ME (ed) *Handbook of Soil Science*. CRC Press: Boca Raton, FL, USA, G-271-G-298

Snapp SS, Silim SN. 2002. Farmer preferences and legume intensification for low nutrient environments. *Plant and Soil* 245: 181–192. DOI: 10.1023/A:1020658715648

Snowball K, Robson AD. 1991. *Nutrient deficiencies and toxicities in wheat: A Guide for Field Identification.* CIMMYT: Mexico, D.F.

Steward PR, Dougill AJ, Thierfelder C, Pittelkow CM, Stringer LC, Kudzala M, Shackelford GE. 2018. The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments : A meta-regression of yields. *Agriculture, Ecosystems and Environment* 251: 194–202. DOI: 10.1016/j.agee.2017.09.019

Thierfelder C, Cheesman S, Rusinamhodzi L. 2012. A comparative analysis of conservation agriculture systems: Benefits and challenges of rotations and intercropping in Zimbabwe. *Field Crops Research* 137: 237–250. DOI: 10.1016/j.fcr.2012.08.017

Thierfelder C, Chisui JL, Gama M, Cheesman S, Jere ZD, Trent Bunderson W, Eash NS, Rusinamhodzi L. 2013. Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. *Field Crops Research* 142: 47–57. DOI: 10.1016/j.fcr.2012.11.010

Thierfelder C, Matemba-Mutasa R, Rusinamhodzi L. 2015a. Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. *Soil and Tillage Research* 146: 230–242. DOI: 10.1016/j.still.2014.10.015

Thierfelder C, Rusinamhodzi L, Ngwira AR, Mupangwa W, Nyagumbo I, Kassie GT, Cairns JE. 2015b. Conservation agriculture in Southern Africa: Advances in knowledge. *Renewable Agriculture and Food Systems* 30: 328–348. DOI: 10.1017/S1742170513000550

Thierfelder C, Wall PC. 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil and Tillage Research* 105: 217–227. DOI: 10.1016/j.still.2009.07.007

Thierfelder C, Wall PC. 2010. Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. *Journal of Crop Improvement* 24: 113–121. DOI: 10.1080/15427520903558484

Trogrlić RŠ, Wright GB, Duncan MJ, van den Homberg MJC, Adeloye AJ, Mwale FD, Mwafulirwa J. 2019. Characterising local knowledge across the flood risk management cycle: A case study of Southern Malawi. *Sustainability (Switzerland)* 11. DOI: 10.3390/su11061681

Tukey JW. 1949. Comparing Individual Means in the Analysis of Variance. *Biometrics* 5: 99. DOI: 10.2307/3001913

Walters DT, Auklakh MS, Doran JW. 1992. Effects of Soil Aeration, Legume Residue, and Soil Texture on Transformations of Macro- and Micro Nutrients in Soils. *Soil Science* 153: 100–107

Whitfield S, Dougill AJ, Wood B, Chinseu EL, Mkwambisi D. 2014. Conservation Agriculture in Malawi: Networks, Knowledge Gaps and Research Planning. Report on the National Conservation Agriculture Research Planning Workshop. 26

Chapter 4

Why we should rethink 'adoption' in agricultural innovation: Empirical insights from Malawi

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Abstract

The challenges of land degradation, climate change and food insecurity have led to the introduction of Conservation Agriculture (CA) aimed at enhancing yield and soil quality. Despite positive biophysical results, low adoption rates have been the focus of studies identifying constraints to wider uptake. While the adoption framework is popular for measuring agricultural innovation, objective adoption measurements remain problematic and do not recognize the contextual and dynamic decision-making process. This study uses a technographic and participatory approach to move beyond the adoption framework and understand: (a) how agricultural decision-making takes place including the knowledge construction, (b) how agriculture is performed in a context of project intervention and (c) how practice adaptation plays out in the context of interacting knowledge. Findings confirm that farmer decision-making is dynamic, multidimensional and contextual. The common innovation diffusion model uses a theory of change, showcasing benefits through training lead farmers as community advocates and demonstration trials. Our study shows that the assumed model of technology transfer with reference to climate-smart agriculture interventions is not as linear and effective as assumed previously. We introduce four lenses that contribute to better understanding complex innovation dynamics: *(a) social dynamics and information transfer, (b) contextual costs and benefits, (c) experience and risk aversion*, and (d) *practice adaptation*. Investments should build on existing knowledge and farming systems including a focus on the dynamic decision process to support the 'scaling up, scaling out and scaling deep' agenda for sustainable agricultural innovations.

Keywords: Climate-smart agriculture, conservation agriculture, Malawi, no-tillage, scaling, southern Africa

4.1 Introduction

To improve the resilience and adaptation of agriculture to climate change threats and land degradation, the Food and Agricultural Organization of the United Nations (FAO) proposed the climate-smart agriculture framework, of which conservation agriculture (CA) is widely promoted across southern Africa (Lipper *et al.*, 2014). CA is a set of technologies, based on three key practices: (a) minimum soil disturbance (no-tillage or zero-tillage); (b) soil surface cover with crop residues or cover crops; and (c) crop rotation or diversification with inter-cropping (FAO, 2015). It has been widely promoted as a land management practice to maintain and enhance soil quality and yields (Thierfelder *et al.*, 2015). However, CA adoption rates in countries such as Malawi have remained low, with a reported 5–6% of the arable land farmed using CA (Kassam *et al.*, 2019). This has been the subject of various studies measuring adoption, identifying adoption constraints and understanding dis-adoption (Chinseu *et al.*, 2019; Ngwira *et al.*, 2014; Thierfelder *et al.*, 2015; Ward *et al.*, 2018).

Agricultural innovations are often conceptualised as a technical package of practices, distributed to new areas with the help of instruction (Glover *et al.*, 2017), with adoption rates representing a primary way of measuring success and impact of this distribution (Glover *et al.*, 2016, 2019). The processes of adoption and diffusion, that is, expanding the use of agricultural innovation, are often characterised as 'scaling'. However, recent literature has highlighted that scaling occurs across multiple levels and dimensions, which are not always considered (Sartas *et al.*, 2020; Wigboldus *et al.*, 2016). To acknowledge these multiple ways in which scaling can take place, specific scaling types have been defined: upscaling refers to extension of the innovation to higher levels (e.g., national), outscaling to expansion within the same level (e.g., within the community) and deep scaling to a change in the mindset and culture (Moore *et al.*, 2015; Schut *et al.*, 2020). This 'scaling up, scaling out and scaling deep' discourse, a linear diffusion of innovation model, remains popular among development initiatives despite various critiques (Chambers *et al.*, 1989; Glover, 2011). It is embedded in the idea that farmers mainly make individual yes or no decisions with a linear development of replacing old methods with new ones (Glover *et al.*, 2016).

A broad literature on the diffusion of agricultural innovation recognises the importance of context and enabling conditions on shaping technology transfer and adoption dynamics (Whitfield *et al.*, 2015; Zanello *et al.*, 2016). Moreover, attention is required on the dynamic connection between the farmer and the system context, which co-evolve and adapt in relation to each other (Engler *et al.*, 2019). Drawing on science and technology studies (STS), there is also an emergent critical response to simplistic narratives around the 'rational' adoption of successful technologies, highlighting the socially constructed and contested nature of agronomic knowledge (Sumberg, 2017). A focus on metrics of adoption overlooks the important processes and decision-making through which innovation happens on farms and may miss out on considering the prerequisite conditions (Sumberg, 2005), namely if the technology is needed and suitable to potential users and local contexts. It also fails to recognise the multiple ways in which farmers do not simply adopt, but continually experiment with and adapt technologies to these contexts (Whitfield, 2015). Therefore, both technology implementation constraints, and the ways in which farmers engage with these constraints, also termed tinkering (Higgins *et al.*, 2017), are contextual and heterogeneous.

Objective measuring of CA adoption remains problematic (Andersson & D'Souza, 2014; Giller *et al.*, 2015) due to the definition of practices that constitute CA and the spatial (e.g., area covered), quality (e.g., how many practices of what) and temporal (e.g., how many seasons) thresholds when it 'counts' as adoption. For example, a systematic review has shown that few papers discussing technology adoption adequately define what adoption is (Loevinsohn *et al.*, 2013). Therefore, questions have been raised in terms of the validity of adoption statements (Andersson & D'Souza, 2014; Brown *et al.*, 2017; Giller *et al.*, 2015).

Recent studies have also called for exploring the adaptation of CA to agro-ecological and socio-economic contexts of the targeted smallholder farmers to increase the CA uptake (Brown *et al.*, 2018b, 2018a; Thierfelder *et al.*, 2015). In order to 'measure' adoption, the question of 'what is CA' is important and often found to be challenging (e.g., land size, time, all practices) ranging from technical definitions to farmers self-defining CA (Hermans *et al.*, 2020). With adoption or non-adoption used as a measure, adoption in itself has become a metric of success for policies or development programmes.

There is a building portfolio of evidence across southern Africa that the science of new agricultural practices does not directly translate into farmers' implementation (Bell *et al.*, 2018; Giller *et al.*, 2009; Ndah *et al.*, 2018; Ngwira *et al.*, 2014; Ward *et al.*, 2018). The agronomically designed top-down 'fixed' package is designed with a focus on biophysical improvements and is often not fully suitable for the local adaptation it will undergo. Methodologies and research are needed that acknowledge the differences, negotiations and conflicts in processes of agricultural decision-making including contextualization (Thompson & Scoones, 1994).

Technography is the social science methodological approach describing technology-in-use and can support other approaches, such as participatory approaches or system theories (Glover, 2011; Jansen & Vellema, 2011). It can be used as a tool to understand the contextualized processes through which agricultural practices are decided upon, insights into how and why certain practices are implemented, and how they differ between farmers (Glover, 2011). It also enables the understanding of the temporal aspect in farmer decision-making. The approach uses a social constructivist underpinning, namely that knowledge and realities of farmers are continually shaped by contextual interactions and experiences. This is supported by the analytical framework of 'agriculture as performance', which emphasizes that farmer decision-making is a reaction in a certain moment embedded in a social and ecological context (Richards, 1989, 1993). The technography approach promotes more open questions about how farmers make decisions when the new technologies are introduced and how this leads to agricultural practice change.

In this paper, we use a method based on technographic and participatory approaches, to rethink and move beyond the concept of 'adoption' or 'non-adoption'. Our aim is to understand farmer decision-making after the introduction of CA in two communities in Malawi and to explore the dynamics and nuance of decision-making processes. The paper seeks to understand: (a) how agricultural decision-making takes place and how the knowledge for process is constructed, (b) how agriculture is performed in a context of development project intervention, including the interaction around this intervention and (c) how CA practice adaptation plays out in the context of interacting knowledge.

4.1.1 CA in Malawi

Malawi depends on rain-fed agriculture with maize being the major staple food crop, covering 80% of the cultivated land area and the major calorific intake (Ngwira *et al.*, 2012). The traditional practice is to prepare the land manually with a hand-hoe. Planting is often done on ridges made annually with approx. 75–90 cm row spacing (Bunderson *et al.*, 2017; Fisher *et al.*, 2018). This traditional practice results from the focus on soil degradation of colonial policy in southern Africa since the 1930s (Andersson & D'Souza, 2014). Residues are burned, removed or buried in furrows.

Malawi, besides Zambia and Zimbabwe, has been at the forefront of CA promotion in southern Africa since the late 1990s (Andersson & D'Souza, 2014). The first CA initiative was established by the NGO Sasakawa Global 2000 in 1998 and supported by the Malawian government (Dougill *et al.*, 2017; Thierfelder *et al.*, 2013). The Sasakawa initiative promoted minimum tillage and mulch cover among small-holder farmers and provided resources packages, similar to national government starter packs, including NPK fertilizer, urea and improved hybrid maize seeds funded by various donors (Dougill *et al.*, 2017). The set of management practices included planting population instructions (1 seed per station in 75 cm ridges and an in-row spacing of 25 cm) and herbicides, which farmers had to buy themselves (Ito *et al.*, 2007; Ngwira *et al.*, 2014). The "SG2000 package" also received extension support to improve "production management" (Ito *et al.*, 2007: 420). This support has become a characteristic of CA promotion initiatives leading to the association and accusation that CA requires high inputs, and critique on the sustainability of such systems and its resulting adoption (Andersson & D'Souza, 2014; Dougill *et al.*, 2017).

The Malawi CA introduction process was renewed in 2004 through a collaboration between the International Maize and Wheat Improvement Centre (CIMMYT), the Malawi Government Extension Services, and later the NGO Total LandCare (TLC) (Ngwira *et al.*, 2014; Thierfelder *et al.*, 2013). This effort focused on the establishment of demonstration trials in communities that enable discussions on CA technologies to prevent land degradation and yield decline (Ngwira *et al.*, 2014). The theory of change that drove this agricultural research for development project in the communities is that demonstrating benefits through 'demonstration trial plots' and training lead farmers to become community advocates, will lead to a snowballing of rational adoption decisions, building on local interactions and innovation systems.

Currently, CA has been widely promoted by NGOs, government, international research centres and development organisations to improve maize yields and drought resilience. Initial CA advocacy has taken place without the development of a national strategy or guidelines, resulting in agreement about CA as an approved technology in 2013 and the formulation of National Guidelines for its promotion in 2016 through a National Conservation Agriculture Task Force (NCATF) (Dougill *et al.*, 2017). This agenda is still being promoted now.

4.2 Material and Methods

4.2.1 Study sites

This study was carried out in two Malawian communities, which are part of CIMMYT's network of on-farm trials in southern Africa: Mwansambo in the central region and Lemu in the southern region. Both communities have six CA on-farm trial replicates, supported by TLC and Machinga Agricultural Development District (ADD). The trials have the following three main treatments: (a) Conventional practice with ridge and furrow system (CP) prepared with a hand-hoe, and following Sasakawa planting spacing (75 × 25 cm and one seed per station); (b) Conservation Agriculture with sole maize (CAM). In this treatment, there is no tillage and maize (*Zea Mays*) is planted with a dibble stick. Residues are retained as surface mulch; (c) Conservation Agriculture (same as b) with maize and legume inter-crop (CAML): cowpea (*Vigna unguiculata L.)* in Mwansambo and pigeon pea (*Cajanus cajan L.*) in Lemu. All are in annual groundnut (*Arachis hypogaea L.*) rotation with a pigeon pea alley cropping (doubled-up legume system) (Table 4.1).

Table 4.1 Community context indicators including both climate and socio-economic.

Area	Latitude (°)	Longitude (°)	Soil Texture	Rainfall (mm)	Extension	Year CA start	Lineage majority	Distance market
Mwansambo Central Malawi	-13.32	34.11	Sandy Clay Loam	1330-1359	Total LandCare (TLC)	2005	Patrilineal	30 km
Lemu, Southern Malawi	-14.79	35.00	Sandy Loam	605-1226	Machinga ADD (Gov)	2007	Matrilineal	30 km

4.2.2 Methods

A pilot study based on four focus groups and community visits was conducted in October 2018 (Appendix E). Subsequently a triangulation of methods was used to examine agricultural decision-making and drivers of change in agricultural practices. Firstly, focus groups were organized using participatory methods including timelines, mapping and ranking exercises. The focus groups were conducted with the trial farmer group (6 farmers) and groups of non-trial farmers (8–10 farmers). One focus group per community was conducted with trial farmers, and two for each community with groups of non-trial farmers. In total, six focus group discussion events were organized.

This was followed up with semi-structured interviews to understand individual and household decision-making (Appendix D). Interviews focused on diversity and depth to build understanding of farmer variable decision-making. Timelines of agricultural decisions focusing on changes in practice and drivers of these decisions were constructed during interviews. This timeline approach using oral history enabled a discussion of changes in agricultural practice over time and what factors led to these changes (Whitfield & Marshall, 2017). In addition, it approached decision-making over a longer time to avoid bias of the fieldwork year's particular wet season. The one-on-one interviews were based on the six trial farmers and a subsequent snowball methodology to select 12–14 farmers with different relations to the trial per community. In total, 38 interviews were conducted. In addition, ethnographic observation in the farming communities for a duration of 3–4 months was conducted (Jansen & Vellema, 2011).

Written consent was obtained from all participants before interviews. It was clarified that the interview had no influence on the participation in any programme. Ethical consent for this research was granted by the Environment Faculty Research Ethics Committee at the University of Leeds (AREA 17–147) and Lilongwe University of Agriculture and Natural Resources. Pseudonyms have been applied to anonymize participant identities.

The case-studies presented were selected to showcase the diversity, multidimensionality and complexity in farmer decision-making and practice experimentation and adaptation. The cases were selected from both communities regardless of its agro-ecology and social makeup (patrilineal/matrilineal) to support exploring this diversity, since the theory of change for the diffusion model is applied in both communities. While the cases are diverse and contextual, they represent the (non-linear) ways in which farmer decision-making and practice implementation take place for the wider population. Therefore, case-study analysis still provides relevant representation and validity for a bigger scale (Flyvbjerg, 2006).

4.3 Results

The following case studies are the stories of seven individuals from the CA trial hosting communities. Their relation to the on-farm trials differs from trial farmers to farmers with no direct connection to the trials (see Figure 4.1).

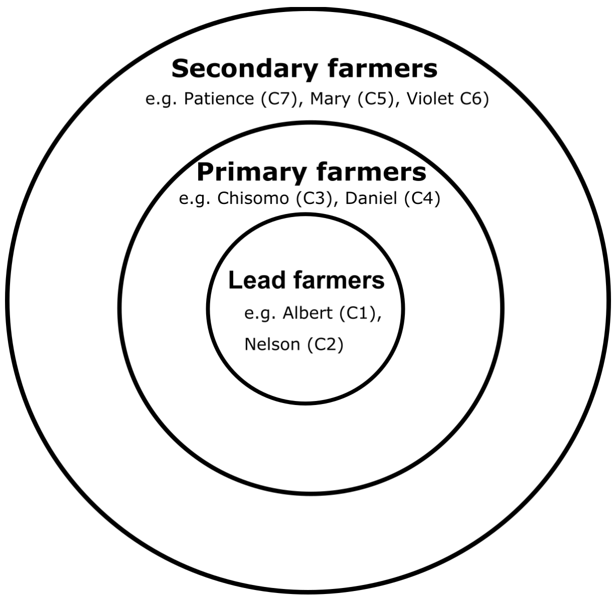

Figure 4.1 This model shows the linear diffusion of innovation model, where demonstration plots and trained lead farmers are the source of information for new agricultural practices. They will be community advocates which should lead to a snowballing of other community farmers implementing the new agricultural innovation. Primary farmers have a direct and regular connection to the lead farmers. Secondary farmers have no direct connection to a lead farmer but receive information via other community members or trial observation when passing by. The case studies are selected along these groups, but will show no perfect model fit. C refers to case study number.

It is important to note that the definition of promotional 'packages' such as CA and Sasakawa is sometimes defined differently by the farmers, who may just refer to sub-practice (components) from the package. Sasakawa, among the farmers, in this case just refers to the spacing introduced with Sasakawa Global 2000 (75 × 25 cm ridges and one seed per station), thus not the practices of residue retention or minimum soil disturbance. In the case of CA, the practices are named separately when referred to, or as all three practices in the full CA package.

4.3.1 Case 1: The 'lead' farmer

One of the farmers who maintains a demonstration trial is Albert. The main income of his household is farming groundnut, maize, pigeon pea, sweet potato and cassava. He runs a CA trial, for which he had the 'courage' to start because he was told he would receive fertilizer, seeds and herbicides.

> *"In the third year of the trial, was when they told us we need to do what we do in the trial also in our own field."*

Following this idea, outside the trial he practices 0.1 ha of CA and on the remaining 0.8 ha of maize, he plants on ridges with burying crop residues *("...for soil fertility*") due to a variety of reasons including land tenure. He rents land every year although the size depends on the money available. He mentions that customary land law prescribes that they do not rent for more than 3 years because otherwise the owners are afraid the renters start to treat it like their own land. Due to this, he does not see the benefits of a practice change to invest in soil fertility and will only practice conventional agriculture on the rented land.

The unpredictable weather is problematic for his choice of agricultural practice. He knows CA is good when it is dry, which is why he promotes it since there have been more dry spells. However, he also stresses that:

> *"CA is not good when the heavy rains come, but I do not know [when] so I do not know what to do anymore".*

In his view, if there is a lot of rain it is better to do the conventional ridge and furrow system, since the ridges keep the maize up high and out of waterlogged conditions. That is why he does both practices on his own land. He does not practice CA for groundnut, because he believes groundnut does not do well with residues.

4.3.2 Case 2: The 'options open Chief' farmer

Demonstration plots on major roads are run by well-connected and respected farmers, which help the distribution of innovations according to the theory of change. Nelson is one of the trial farmers who has a demonstration trial near a major community road and is also a Chief, and thus a well-respected member of the community.

Starting from 2005, he always did 'Sasakawa', but this year his wife was ill so they could not afford the needed fertilizer, which has to be applied to more planting stations with Sasakawa. Traditionally, farmers are applying the fertilizer by station with a bottle-top, instead of applying the fertilizer per area, which explains the difference in fertilizer requirement. Due to health expenses, he also decided not to do his usual 0.4 ha of CA because they could not get the herbicides. There has been a previous season, in 2014/2015, where he decided not to do 0.4 ha of CA. That season there was too much rain, which meant the soil held too much water and the fertilizer did not work.

For his 1 acre of CA, he imports additional maize residues because the mix of his groundnut and maize residues is not enough in his view. Whenever he is unable to do CA or Sasakawa, he makes ridges with buried residues, like this year. He was given instructions that burying is better because it restores the soil and builds soil fertility, whereas burning does not add anything. He commented that:

> *“I chose to do ridges because I am used to it and it is easier. I find flat ground with planting and fertilizer too involving.”*

If there are ridges and he does not find the money for herbicides or fertilizer, he can always do ridge weeding with a hoe. Although CA has better yields in his opinion, particularly when there is little rain. When he started the trial on his field, he expected to see improvement in yield, soil fertility and drought resistance, and his expectations were rewarded. However, the expectations he had about it being labour and cost effective were not met, due to more labour for planting and fertilizer application, in response to a higher plant population and residue import.

4.3.3 Case 3: The ‘first step progress’ farmer

One of the farmers who interacts directly with lead farmer Nelson is Chisomo. He lives near the demonstration trial of the community chief, with his wife and five children. When the Chief's trial started, he was invited to see the trial and listen to the extension officer. They were introduced to CA and Sasakawa, and he noticed on the trial that the yield improved. After listening to what the extension officer said and what he noticed on the trial for years, he summarized:

> *“They [extension officers] encourage both CA and Sasakawa, but more [people] do Sasakawa because people think it is easier compared to CA. Sasakawa is perceived easier*

> *because you do not need to import residues. You only have to make ridges 75 cm apart and then plant, whereas on CA you have to do the same in the first place - make 75cm planting rows but then also import residues."*

If he has enough fertilizer from the subsidy, he uses Sasakawa for 0.1 ha, which he finds manageable in terms of resources and breaking up the ridges from 90 cm to 75 cm. On the rest of the fields, he continues with making ridges and burying the residues, like most of them in the community do.

Burying residues, which he learned improves soil fertility, is not more work, unlike residues on top like in CA. He explains that:

> *"Ridges is what farmers believe in. They make ridge and then planting the seeds, then weeding, then banking. So, it becomes hard to adopt a new system."*

At the same time when CA was introduced, they were told that if they feel CA is too difficult, then they can keep ridges. Others may adopt CA because they see the benefits of CA and find it worth the effort. In his own experience, the soil gets hard on the flat land, especially when there are insufficient crop residues, whereas the ridges make the soil soft again, which makes it easier for maize to grow.

4.3.4 Case 4: The 'distributing benefits' farmer

Besides direct lead farmer or trial connections, there are also informal routes for innovation diffusion. In 2009, Daniel was invited to the Chief's house where the TLC extension officer told him about CA. He was interested and noted that the government extension officer remained quiet because "*...he had given advice against the TLC officer before*." According to him, the quietness of the government officer suggests the TLC officer was right.

It took him 2 years to be convinced about the benefits of CA, but since 2011, he consistently practices 0.2 ha of CA on his own land. He was motivated by the contact with the TLC extension officer but also because he ran out of time at some point to clear the field as usual. This shortage of time gave him no other option but to leave the residues on the field, and, to his surprise, he noticed the yield improved that season. After some confusion about where the 0.2 ha CA is, he explains that this 0.2 ha of CA moves around every season. This way the whole field enjoys improvement in soil fertility. If he sees the residues are not sufficient or the weeds are problematic, he decides to heap up the soil (bank) to control the weeds.

Since he knows the soil needs to be well covered, he imports the residues and also takes some from the neighbours who would burn them otherwise. This collection is enough for 0.2 ha in order to cover the field to the level that ridges are not needed, as observed on the trial.

For all his other fields he just plants the maize on old ridges, without renewing them and banks when weeding is needed. In the past, when he made new ridges, the rain would come and wash them away. So, when TLC introduced the planting on old ridges, many of the farmers in the community liked it, making it now a common practice. To help his work on the land, he hires labour but he would never do that for his 0.2 ha CA because they mess it up or ask for more money.

4.3.5 Case 5: The 'age adapter' farmer

Mary is excited to talk about the 3-year system she uses to cultivate because she wants to minimize the labour due to her husband's and her poor health. She thought of this in 1994 when she was late with land preparation due to her teaching job. She notes that the first year is the most work when new ridges are made including the burying of residues. In the next 2 years, she leaves the ridges without splitting them to make new ridges and places the residues between them. Once she completes weeding, she places them on the ridges. For these 2 years of no-tillage, she also does not need to spend money on hiring labour. The old ridges are also good for her land because the strong old ridges will not wash away easily on the slope.

Since she had to pay school fees for children, she could never buy fertilizers, so she liked the idea of burying crop residues that still improve soil fertility. She started burying residues when she moved away from her parents, after learning from neighbours that residues improve soil fertility.

> *"Adding residues is the only way people can cultivate without fertilizer."*

Despite her preference, due to poor health, to avoid making ridges, she sees it as necessary to make new ridges every 3 years because otherwise her clay soil gets too hard.

When she is lucky to be part of the fertilizer subsidy programme, she can do Sasakawa on a smaller piece of land she rents, which will give her more yield than normal, particularly when there is a drought. She tried doing this since she was invited to a field day at a trial 5 minutes from her house. For her other field, she never considers Sasakawa because it is too big.

> *"The big field is fertile, but Sasakawa can only be done with hybrid seeds and these seeds need fertilizer."*

She tried hybrids on the big field 4 years ago but without fertilizer, which resulted in very poor yields. Based on her parents farming she continued to intercrop through the fields. For the groundnut fields, she noticed on the demonstration trials that farmers are applying residues, but she believes residues are not good for groundnut so she has not changed the practices. While these practices are described as normal, she does admit that she gets mocked as being lazy for her 3-year system by others. She does not like this since *"...people want to be admired to work hard*" - but her health does not give her many options.

4.3.6 Case 6: The 'female family caregiver' farmer

In a house far from the main road and not easily accessible lives Violet. This divorced farmer has five children but takes care of nine people in total in her household. She farms, burns charcoal and works in other people's fields and on a roadside development. Furthermore, she had to rent out 1.6 ha because of her financial problems.

Due to all her livelihood supporting jobs, she wants as little work as possible on her fields. That is why she burned the residues this year and planted them on old ridges. On the fields where the children helped her, they made new ridges, because her children oppose to not making new ridges despite her own observation that maize does better when planted on old ridges. In 2008, she did Sasakawa and CA on 1 acre, but she felt intimidated by others. People were laughing that the plants were so close to each other and will not do well. They said:

> *"...it takes you more time to plant 1 seed per station so you will be the last to finish planting."*

She also heard residues will bring fall armyworm. The next year she did it only on 0.1 ha. She still kept the 0.1 ha Sasakawa because the yield was good. The others still disparaged but 0.1 ha was acceptable by them as a test.

Right now, peoples' mindset is changing, due to the trials. She mentions that the conventional practice is the easiest and that the new practices are not useful. There are two things that make the new practice hard: (a) not enough fertilizer and herbicides, (b) putting residues on the field. On the main road, she noticed the trial farmers stopped importing residues but now there are not enough residues on the trial fields. She knows that the practice on the trial started with support so

> *"...everyone expects that support is needed to start."*

She says that most of them think that the trial farmers do it only because they get support and are the extension officer's farmers. The extension officer is limited in where he can help, which she also reports as the cause of one of the main challenges, namely the lack of knowledge. Information is not shared properly via the lead farmers and

> *“...there is only one lead farmer per village so they also cannot cover all.”*

4.3.7 Case 7: The ‘disappointing experience’ farmer

The CA demonstration trials are not the only trials in these communities. There is a history of other organisations, such as National Smallholder Farmers' Association of Malawi (NASFAM), also using demonstration trials to showcase new agricultural practices. Patience is one of the farmers who was involved with another NASFAM demonstration trial.

She was a member of NASFAM, for which she paid a membership fee but received free groundnut seeds. She only did this for one season because NASFAM did not get back to her about it and she was not reimbursed. She just followed what they told her to do but she did not observe a change. Overall, she liked the trial system but did not expand and burned the residues again, which she continues to do now. Since nobody put effort in the trial or told her the objectives, she did not feel like continuing the practice. With the current CA trials, she mentions that

> “*Most people think only the trial [lead] farmer was chosen to do that farming. He was chosen by TLC.”*

The extension officer never comes to her area so she struggles to contact him and would not know how to start the new practice by herself. In particular, planting with a marked string looks complicated and too involving. She never asked anything herself to the lead farmer, but the extension officer could tell her more in detail because he went to school and was trained.

On her own field, she has good maize so she does not feel compelled to change but she would like to know from the extension officer about how to do certain things.

4.4 Discussion

The various stories of individuals in these communities hold within them themes that contribute to a more nuanced understanding of adoption and innovation dynamics, which are often overlooked in linear innovation diffusion discourse. In the following section we highlight and discuss four lenses that can contribute to our understanding of farmer decision-making: *social dynamics and information transfer, contextual cost and benefits, experience and risk aversion, and practice adaptation*.

4.4.1 Lens 1: Social dynamics and information transfer

Farm-level knowledge and decision-making are socially constructed have been recognised in an emergent STS literature (Glover *et al.*, 2016; Whitfield, 2015) and critical extension studies (Leeuwis & Van den Ban, 2004). In the case of CA in Malawi, we have seen how social dynamics shape farmers' perceptions and experiences of innovation, including decisions about whether and at what points to engage with or disengage from a process of trialling new practices.

Decision-making does not only include economic or technical dimensions as social acceptability is also important. Family members' help on the field and their opinion make implementing agricultural practice change unlikely because they want to make ridges. Only 0.1 ha seems feasible in terms of social dynamics due to the social approval of it as a 'trial'. Others were intimidated or mocked for being 'lazy'. This wording comes up frequently in farmer discussion, showing that not making ridges is still associated with 'laziness', whereas 'hard-working' is seen as the virtue for a farmer to be food secure. This is contradicting, since a perceived increase in labour, related to the planting without ridges and residue retention, is also seen as discouraging CA. On the other hand, the release from making ridges is also a motivation in favour of CA. Therefore, it seems labour remains a contested topic with beliefs, consideration of total season labour (Thierfelder *et al.*, 2016) and its timing.

Social acceptability is associated with community group dynamics and connected flow of information. Farmers observed from the trial that support was given to start CA. This makes farmers think they need that same support to make the change work, leading to a belief that it is not worth trying on one's own. The trial farmers are part of the club and the farmers receive extension officer's attention and support. Even farmers who implemented CA on their own feel they are part of the club with access to information on modern technology. A distinct problem is that while the theory of change of demonstration trials and farmer to farmer distribution assumes homophily (i.e., people in the community are equal) (Rogers, 2003), the group dynamics create heterophily, which makes the diffusion of innovation not as effective.

There are beliefs and social dynamics in the community that are also of importance to farmers' decision-making. For example, the general belief that residues are not good for groundnut, despite data showing more harvest under CA (Bunderson *et al.*, 2017). Similarly, the increase of planting population under Sasakawa creates the belief of higher fertilizer need. However, less fertilizer per plant leads to similar fertilizer need per area. The consensus of what is sufficient residue is different among farmers, and based on the CA introduction and trials, residue import to create a thick layer was needed. These instructions have now changed to just leaving leftover residues but the idea of 'sufficient' seems to still differ between farmers. The concept of 'residues being a limiting factor' may therefore be based on the belief on how much is sufficient. In the narrative of residues, the belief of residue import risking disease transfer (e.g., fall armyworm) is widely accepted, although proliferation of fall armyworm through crop residues is uncommon and only applies to stalk borers. This shows that having access to information can support practice change but common beliefs may counteract this.

The closeness to a trusted source of information affects the belief in the validity of the information (Fisher *et al.*, 2018; Holden *et al.*, 2018). Farmers in direct contact with the extension officer trust and implement more of the information, than when it comes to indirect ways such as trial observation or other community farmers. Some state that the lead farmer dissemination approach works since they are closely connected, whereas others note that this does not work. As previously reported in Brown et al. (2020), farmers report problems with information sources and lack of training due to lack of contact with extension officer and lead farmers. Alternatively, studies by Cofré-Bravo et al. (2019) have shown that there is a wide variety in the configuration of knowledge and support networks used by farmers, depending on livelihood, farm and innovation goals. In this light, the focus on lead farmers to instigate innovation diffusion does not fully accommodate the diversity in knowledge and support networks. The assumed model of technology transfer, which relies on expanding social connections, leading to information transfer that turns into implementation, as illustrated in Figure 4.1 may not be as linear and effective.

4.4.2 Lens 2: Contextual costs and benefits

As recognised in diffusion theory (Rogers, 2003), sustained engagement with a new innovation depends on whether or not there is a relative advantage of the new practice over the current practice. An assessment of relative advantage includes a consideration of the compatibility of innovation with the existing context. While diffusion theory acknowledges that context plays a role, this is often limited to biophysical or technical factors or assumes linear and rational decision-making, thereby not addressing the full multi-dimensionality and dynamic decision-making process. The case of CA in Malawi helps to demonstrate that there are a complex set of contextual costs and benefits that shape decision-making, and that these are themselves socially constructed.

Farmers consider the balance between costs and benefits for their context. This is not only economic but also includes social and ecological aspects and the intangible 'cost' of changing to something new. Two economic elements that increase the 'costs' or lower the benefits are rented land and hired labour. On rented land, the benefits of practices perceived as CA are not experienced, and in hiring labour, oversight is needed or more remuneration. Another economic aspect is that practice implementation is dependent on the fertilizer subsidy received that year. In most cases, the major challenge to agricultural improvement is identified as access to the resources. This challenge is associated with the belief that CA systems can only be applied with high input packages. Farmers do not have the 'courage' to try new practices because they do not get the resource or knowledge support, they feel they need.

Other factors also play a role in the contextual balance. Farmer experimentation and adaptation are based on health and labour concerns (e.g., ridge making labour, residue import, string planting) and agro-ecological dimension (e.g., soft soil, land slope). Some farmers know the benefits but the perceived effort costs are too high. Benefits from residue are most evident during droughts, which provide a convincing entry point. However, it was also mentioned that the year after a drought there are very little residues, thereby increasing the challenge of residue retention. Over the farming season, these factors interact and are affected by the context's institutions and structures, creating reinforcing cycles of productivity, health, resource access and labour (Jew *et al.*, 2020). The benefits need to be sufficient and address the farmers' needs and challenges, which are dynamic and focused on short-term benefits rather than longer-term sustainability.

The balance of costs and benefits is contextual and can be dependent on the introduction of other changes in agricultural practices, such as planting on old ridges, Sasakawa planting or residue burying. The common methods of old ridges and banking are also seen as an improvement, which saves work. The observation of the trial farmer importing the residues, the agro-ecological observations and the government message that Sasakawa planting is already an improvement forms the beliefs of costs and benefits. The burying of residues for soil fertility improvement was easily adopted than the CA package because the cost was low compared to the benefit. Mentioning of ‘others may find it worth it’ shows that the cost and benefit balance is individualistic, addressing the challenges given by Glover (2011) that decision-making is multidimensional and dynamic.

The contextualization and livelihood dependency of the costs and benefits balance (Farnworth *et al.*, 2016; Mutenje *et al.*, 2019) can especially be elaborated in Violet's case. It is representative of various female farmers interviewed who are divorced, separated or widowed. They have additional jobs, which become the focus of cash income. There is shortage of labour for their fields and there is no money for herbicides or hired labour to replace that work, particularly weeding. A change of practice is observed as too much work and effort (including the learning process). This shows the livelihood context of decision-making and shows that there is a risk in change, which comes with intangible costs that for some are not worth the benefits.

4.4.3 Lens 3: Experience and risk aversion

In the context of complex costs and benefits, particularly for resource-constrained farmers, a risk-averse approach to new technologies and investments may predominate (Whitfield, 2015). We also see, in this case, how past experiences of technologies and interventions can contribute to an aversion to risk. This is evident in the cases of disengagement or small-scale and incremental experimentation with CA practices.

Individual experiences play a role and show that current decision-making is not only rational. For example, disappointment with a previous trial project, not understanding its purpose, lack of observable improvement and contact with extension officer all create less willingness to change practice again. There is a lack of feeling involved or ownership of the trial. This was also reported in Brown et al. (2020), who highlighted that lead farmers did not understand that they can expand beyond the trial. The farmer stories present that decision-making can result from information flow interacting with personal (sometimes accidental) experimentation.

Risk-averse behaviour to keep options open also guides farmers' decision-making. One main challenge is the uncertainty of the weather. Risk is spread by using both the conventional practice in case of heavy rains and the perceived CA practices, of which the main focus is residue retention, in case of droughts (Ngwira *et al.*, 2013). The conventional method is seen as leaving options open in case the resources cannot be found because banking and weeding with a hoe can be done. Other strategies are the back-up plan of banking in case the weeds still get through the residue layer.

4.4.4 Lens 4: Practice adaptation

In agricultural innovation, we rarely see a linear perfect and whole-scale replacement of old practices by new ones (Glover, 2011). The adaptation or 're-invention' of practices shows that there is change in the used agricultural practices, which can be beneficial for sustainability of the implementation of new practices (Rogers, 2003). As such, there may not be a single moment of technology adoption or a clear distinction between those that do and those that do not adopt a technology, which emphasizes the dynamic process (Kiptot *et al.*, 2007). Rather, as in the case of CA in Malawi, we might observe a continually changing mosaic picture of resultant practices, across space and time, which reflect the socially constructed knowledge, local costs and benefits, and risk aversion and experimentation of different farmers.

Farmers use CA information and experimentation, and implement this in various manners, as has also been mentioned in CA adaptation literature (Brown *et al.*, 2018b, 2018a). There is hybridization of old and new practices. In particular, Sasakawa planting is seen as a modern agricultural improvement and a step towards the perceived CA package but without removing the ridges. The CA package introduction included the first year with Sasakawa planting with residues retention and the conventional field in the on-farm trials is also Sasakawa planting. There are associated costs with Sasakawa planting such as fertilizer and labour for breaking up the ridges for the first time. However, it is seen as using improved modern techniques, but does not meet the costs or investment that comes with perceived CA practices (e.g., residue retention). Planting on old ridges and banking is also a variation moving forward from the old practices and can be found in the CA package introduction where ridges should not be remade. Therefore, farmers, in their own way, negotiate and work with constraints, a process also called tinkering (Higgins *et al.*, 2017), to use new information on agricultural innovation.

Other dynamic implementations are on temporal and spatial scales. New practices are done on limited land areas, most frequently in 0.1 or 0.2 ha, the usual trial size, for various reasons including social acceptance and labour limitations. Alternative strategies include moving the 0.1 ha around so that the entire land can be improved. On the temporal scales, conscious choices are made to change practices every season due to rainfall or health affecting resources.

While re-invention is often not considered good, it is not necessarily bad once the reasoning behind the choices is understood. Considering the adaptation of practices that is occurring, including an increase in the 'left-over' information from the Sasakawa introduction, crop diversification or residue retention, we notice that farmers are interacting with the introduction of new practices. This response is dynamic and resulting from the interaction of the individual farmer and system context (Engler *et al.*, 2019). The use of information is not always in the exact introduced form but it does allow for the customization to local context (Rogers, 2003). The impact of introduction of new agricultural practices, such as the CA package, is therefore wider than adoption measurements indicate.

The linear based theory of change is connected to the pre-determined adoption measuring framework, since it is based on the view that agriculture innovation diffusion is 'technology transfer'. However, this does not cover the complexity of the agricultural systems and farmers' decision-making. Therefore, both complexity-aware theory of change and evaluation criteria (Douthwaite & Hoffecker, 2017) may be more suitable. This evaluation acknowledges that outcomes can be technological implementation, but also the innovation process, in terms of effectiveness, and to what extent capacity for development, innovation and adaptation within the system have been built up.

4.4.5 Recommendations

Establishing this dynamic process and moving away from an adoption measuring framework, thereby provide empirical insights to the work of Glover (2016, 2019), which shows that there is need to shift investment away from perfecting a technology and instead focus on the process and farming system the innovation can adapt to. This requires considering and exploring the relationship and co-evolution of the farmer decision-making and the system context, which will be increasingly important when scaling agricultural innovation (Engler *et al.*, 2019; Sartas *et al.*, 2020; Wigboldus *et al.*, 2016). Furthermore, this should be paired with a shift to focusing on the end goal, namely the extent needs are met through innovations, instead of the extent of adoption. Funding structures and incentives often reinforce the situation of organisations being tied to the promotion of specific technologies and innovations, and competing to demonstrate the relative advantage, often using adoption rates as a metric of success that reinforces their claim to success (Sumberg *et al.*, 2012). However, shifting focus and incentives to the end goal of innovation could encourage a movement away from narrowly conceived technological solution and focus efforts on the quality of innovation processes. For example, building on adaptation that farmers already implement, such as planting on old ridges, any form of residue retention or the Sasakawa planting. This also provides the opportunity to change the approach to focus on supporting farmers' intrinsic motivation to adapt practices and experiment, thereby acknowledging the differences in farming styles and goals. Projects could therefore learn from these case studies to improve farmers' ownership, empowerment, develop 'complexity-aware' non-linear theory of change and evaluation (Douthwaite & Hoffecker, 2017) and become process facilitators (Kessler *et al.*, 2016) in the change towards improving livelihoods and sustainable agriculture.

Innovation platforms, as also suggested in Schut *et al.* (2016) and Brown *et al.* (2020), including farmer and extension officers can support further development of existing extension, knowledge and practice systems. They can also provide better connection between introduced agricultural packages and community-based agricultural development. To capture and work with dynamic farming systems, including the non-predictable contextual emerging challenges and opportunities, continuous reflection and feedback is important to match the needs and actions (Kilelu *et al.*, 2014). This requires evolving learning processes, through a dynamic learning agenda (Kilelu *et al.*, 2014), in which extension services play an important role. For the 'scaling up, scaling out and scaling deep' discourse, it will be of importance to take into account these dynamic interactions and the ways in which new innovations can be processed into implementation.

4.4.6 Reflection on the approach

The qualitative approach enabled going beyond the adoption measuring framework and associated challenges with CA definitions. It uncovered the diversity in adaptation of practice and how farmers process and interact with agricultural innovation information and interventions. Its focus on depth over large area representativeness has supported the concept of agriculture as performance and the contextualised process of dynamic and multidimensional farmer decision-making, including the temporal aspects (Glover, 2011; Richards, 1989, 1993). The challenges of the adoption measuring framework are embedded in the agricultural systems' problem (Glover *et al.*, 2016), in terms of how these systems are defined, and its dynamics, diversity and complexity acknowledged. This farmer-centred approach, including ethnographic informed interviews, enables a cross-disciplinary look, considering these system challenges for the diffusion of innovation and associated theory of change.

4.5 Conclusion

In this study, a method based on the technographic and participatory approach was used to rethink the concept of 'adoption', understand how agricultural decision-making takes place and how the knowledge is constructed after the introduction of CA in two Malawian communities. The approach has shown that farmer decision-making is dynamic, multidimensional and contextual. There is a large range of interacting factors that play a role in the decision-making at a particular point in time: agro-ecology, health, labour, economics, resource endowment, family size, age, gender, experience, risk aversity, alternative practices available and social dynamics. The trade-offs of these are different for individual farming systems and livelihoods at a certain time. This is dependent on the relative advantage in the individual farmer's perception of change to farming practice.

The theory of change underpinning the common agricultural innovation diffusion model is based on demonstrating benefits through 'demonstration trials' and training lead farmers to become community advocates. Our study has shown that social dimensions, including acceptability and group dynamics, play an important role in farmer decision-making and efficiency of the diffusion model. The level of closeness and trust in the source of information influences agricultural decisions, which balance between new information, level of trust, common beliefs and experience. The assumed model of technology transfer is, therefore, not as linear and effective as often assumed.

Moving beyond the adoption measuring framework has shown that there is a wide diversity in practice adaptation and re-invention. While the re-invention of introduced practices is not always considered positively, it does provide opportunity to adapt to local context and shows the presence of innovation changes. Considering this wider picture of agricultural practice implementation and change, the influence of agricultural interventions and introductions is larger than can be measured in an adoption framework. To capture these dynamics and complex processes of agricultural systems and farmer decision-making, both complexity-aware theory of change and evaluation criteria are more suitable. Investments should increase focus on the dynamic process and fit of innovation in farming systems, considering the mutual adaptation between farmer and system context, instead of solely perfecting a technology. For example, building on already occurring adaptations, such as planting on old ridges or any form of residue retention (mainly burying). The focus on dynamic processes to develop agricultural innovations in farming systems also means agencies can move away from being tied to their specific promoted agronomic solution. To build on the existing knowledge and farming systems, innovation platforms, including farmers and extension staff, and dynamic evolving learning processes, including feedback and reflection, are important to support the 'scaling up, scaling out and scaling deep' agenda for agricultural innovations like CA.

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References

Andersson JA, D’Souza S. 2014. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment* 187: 116–132. DOI: 10.1016/j.agee.2013.08.008

Bell AR, Cheek JZ, Mataya F, Ward PS. 2018. Do as they did: Peer effects explain adoption of conservation agriculture in Malawi. *Water (Switzerland)* 10: 51. DOI: 10.3390/w10010051

Brown B, Llewellyn R, Nuberg I. 2018a. Global learnings to inform the local adaptation of conservation agriculture in Eastern and Southern Africa. *Global Food Security* 17: 213–220. DOI: 10.1016/j.gfs.2017.10.002

Brown B, Nuberg I, Llewellyn R. 2017. Stepwise frameworks for understanding the utilisation of conservation agriculture in Africa. *Agricultural Systems* 153: 11–22. DOI: 10.1016/j.agsy.2017.01.012

Brown B, Nuberg I, Llewellyn R. 2018b. Further participatory adaptation is required for community leaders to champion conservation agriculture in Africa. *International Journal of Agricultural Sustainability* 16: 286–296. DOI: 10.1080/14735903.2018.1472410

Brown B, Nuberg I, Llewellyn R. 2020. From interest to implementation: exploring farmer progression of conservation agriculture in Eastern and Southern Africa. *Environment, Development and Sustainability* 22: 3159–3177. DOI: 10.1007/s10668-019-00340-5

Bunderson WT, Jere ZD, Thierfelder C, Gama M, Mwale BM, Ng'oma SWD, Museka RM, Paul JM, Mbale B, Mkandawire O, Tembo P. 2017. Implementing the Principles of Conservation Agriculture in Malawi: Crop Yields and Factors Affecting Adoption. In: Kassam AH, Mkomwa S and Friedrich T (eds) *Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate.* CABI: Wallingford, UK, 75–99

Chambers R, Pacey A, Thrupp LA. 1989. *Farmer First: Farmer Innovation and Agricultural Research.* Intermediate Technology Publications: London, UK

Chinseu E, Dougill A, Stringer L. 2019. Why do smallholder farmers dis-adopt conservation agriculture? Insights from Malawi. *Land Degradation and Development* 30: 533–543. DOI: 10.1002/ldr.3190

Cofré-Bravo G, Klerkx L, Engler A. 2019. Combinations of bonding, bridging, and linking social capital for farm innovation: How farmers configure different support networks. *Journal of Rural Studies* 69: 53–64. DOI: 10.1016/j.jrurstud.2019.04.004

Dougill AJ, Whitfield S, Stringer LC, Vincent K, Wood BT, Chinseu EL, Steward PR, Mkwambisi D. 2017. Mainstreaming conservation agriculture in Malawi: Knowledge gaps and institutional barriers. *Journal of Environmental Management* 195: 25–34. DOI: 10.1016/j.jenvman.2016.09.076

Douthwaite B, Hoffecker E. 2017. Towards a complexity-aware theory of change for participatory research programs working within agricultural innovation systems. *Agricultural Systems* 155: 88–102. DOI: 10.1016/j.agsy.2017.04.002

Engler A, Poortvliet PM, Klerkx L. 2019. Toward understanding conservation behavior in agriculture as a dynamic and mutually responsive process between individuals and the social system. *Journal of Soil and Water Conservation* 74: 74A-80A. DOI: 10.2489/jswc.74.4.74A

FAO. 2015. *Conservation Agriculture. http://www.fao.org/conservation-agriculture/en/*

Farnworth CR, Baudron F, Andersson JA, Misiko M, Badstue L, Stirling CM. 2016. Gender and conservation agriculture in East and Southern Africa: towards a research agenda. *International Journal of Agricultural Sustainability* 14: 142–165. DOI: 10.1080/14735903.2015.1065602

Fisher M, Holden ST, Thierfelder C, Katengeza SP. 2018. Awareness and adoption of conservation agriculture in Malawi: what difference can farmer-to-farmer extension make? *International Journal of Agricultural Sustainability* 16: 310–325. DOI: 10.1080/14735903.2018.1472411

Flyvbjerg B. 2006. Five Misunderstandings About Case-Study Research. *Qualitative Inquiry* 12: 219–245. DOI: 10.1177/1077800405284363

Giller KE, Andersson JA, Corbeels M, Kirkegaard J, Mortensen D, Erenstein O, Vanlauwe B. 2015. Beyond conservation agriculture. *Frontiers in Plant Science* 6: 1–14. DOI: 10.3389/fpls.2015.00870

Giller KE, Witter E, Corbeels M, Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics’ view. *Field Crops Research* 114: 23–34. DOI: 10.1016/j.fcr.2009.06.017

Glover D. 2011. The System of Rice Intensification: Time for an empirical turn. *NJAS - Wageningen Journal of Life Sciences* 57: 217–224. DOI: 10.1016/j.njas.2010.11.006

Glover D, Sumberg J, Andersson JA. 2016. The Adoption Problem; or Why We Still Understand so Little about Technological Change in African Agriculture. *Outlook on Agriculture* 45: 3–6. DOI: 10.5367/oa.2016.0235

Glover D, Sumberg J, Ton G, Andersson J, Badstue L. 2019. Rethinking technological change in smallholder agriculture. *Outlook on Agriculture* 48: 169–180. DOI: 10.1177/0030727019864978

Glover D, Venot JP, Maat H. 2017. On the movement of agricultural technologies: Packaging, unpacking and situated reconfiguration. *Agronomy for Development: The Politics of Knowledge in Agricultural Research*, 14–30. DOI: 10.4324/9781315284057

Hermans TDG, Whitfield S, Dougill AJ, Thierfelder C. 2020. Bridging the disciplinary gap in conservation agriculture research, in Malawi. A review. *Agronomy for Sustainable Development* 40: 3. DOI: 10.1007/s13593-020-0608-9

Higgins V, Bryant M, Howell A, Battersby J. 2017. Ordering adoption: Materiality, knowledge and farmer engagement with precision agriculture technologies. *Journal of Rural Studies* 55: 193–202. DOI: 10.1016/j.jrurstud.2017.08.011

Holden ST, Fisher M, Katengeza SP, Thierfelder C. 2018. Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land Use Policy* 76: 113–123. DOI: 10.1016/j.landusepol.2018.04.048

Ito M, Matsumoto T, Quinones MA. 2007. Conservation tillage practice in sub-Saharan Africa: The experience of Sasakawa Global 2000. *Crop Protection* 26: 417–423. DOI: 10.1016/j.cropro.2006.06.017

Jansen K, Vellema S. 2011. What is technography? *NJAS - Wageningen Journal of Life Sciences* 57: 169–177. DOI: 10.1016/j.njas.2010.11.003

Jew EKK, Whitfield S, Dougill AJ, Mkwambisi DD, Steward P. 2020. Farming systems and Conservation Agriculture: Technology, structures and agency in Malawi. *Land Use Policy* 95: 104612. DOI: 10.1016/j.landusepol.2020.104612

Kassam A, Friedrich T, Derpsch R. 2019. Global spread of Conservation Agriculture. *International Journal of Environmental Studies* 76: 29–51. DOI: 10.1080/00207233.2018.1494927

Kessler CA, van Duivenbooden N, Nsabimana F, van Beek CL. 2016. Bringing ISFM to scale through an integrated farm planning approach: a case study from Burundi. *Nutrient Cycling in Agroecosystems* 105: 249–261. DOI: 10.1007/s10705-015-9708-3

Kilelu CW, Klerkx L, Leeuwis C. 2014. How Dynamics of Learning are Linked to Innovation Support Services: Insights from a Smallholder Commercialization Project in Kenya. *Journal of Agricultural Education and Extension* 20: 213–232. DOI: 10.1080/1389224X.2013.823876

Kiptot E, Hebinck P, Franzel S, Richards P. 2007. Adopters, testers or pseudo-adopters? Dynamics of the use of improved tree fallows by farmers in western Kenya. *Agricultural Systems* 94: 509–519. DOI: 10.1016/j.agsy.2007.01.002

Leeuwis C, Van den Ban A. 2004. *Communication for Rural Innovation Rethinking Agricultural Extension.* Blackwell Science Ltd: Oxford, UK. DOI: 10.1002/9780470995235

Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen PT, Sessa R, Shula R, Tibu A, Torquebiau EF. 2014. Climate-smart agriculture for food security. *Nature Climate Change* 4: 1068–1072. DOI: 10.1038/nclimate2437

Loevinsohn M, Sumberg J, Diagne A, Whitfield S. 2013. *Under what circumstances and conditions does adoption of technology result in increased agricultural productivity?* Brighton, UK

Moore M-L, Riddell D, Vocisano D. 2015. Scaling Out, Scaling Up, Scaling Deep: Strategies of Non-profits in Advancing Systemic Social Innovation. *Journal of Corporate Citizenship* 2015: 67–84. DOI: 10.9774/gleaf.4700.2015.ju.00009

Mutenje MJ, Farnworth CR, Stirling C, Thierfelder C, Mupangwa W, Nyagumbo I. 2019. A cost-benefit analysis of climate-smart agriculture options in Southern Africa: Balancing gender and technology. *Ecological Economics* 163: 126–137. DOI: 10.1016/j.ecolecon.2019.05.013

Ndah HT, Schuler J, Diehl K, Bateki C, Sieber S, Knierim A. 2018. From dogmatic views on conservation agriculture adoption in Zambia towards adapting to context. *International Journal of Agricultural Sustainability* 0: 1–15. DOI: 10.1080/14735903.2018.1447227

Ngwira AR, Johnsen FH, Aune JB, Mekuria M, Thierfelder C. 2014. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. *Journal of Soil and Water Conservation* 69: 107–119. DOI: 10.2489/jswc.69.2.107

Ngwira AR, Thierfelder C, Eash NS, Lambert DM. 2013. Risk and Maize-Based Cropping Systems for Smallholder Malawi Farmers Using Conservation Agriculture Technologies. *Experimental Agriculture* 49: 483–503. DOI: 10.1017/S0014479713000306

Ngwira AR, Thierfelder C, Lambert DM. 2012. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems* 28: 350–363. DOI: 10.1017/S1742170512000257

Richards P. 1989. Agriculture as a performance. In: Chambers R, Pacey A and Thrupp LA (eds) *Farmer First: farmer innovation and agricultural research.* Intermediate Technology Publications: London, 39–42

Richards P. 1993. Cultivation: knowledge or performance? In: Hobart M (ed) *An Anthropological Critique of Development:The Growth of Ignorance.* Routeledge: New York, 61–78

Rogers EM. 2003. *Diffusion of innovations.* The Free Press: New York, NY

Sartas M, Schut M, Proietti C, Thiele G, Leeuwis C. 2020. Scaling Readiness: Science and practice of an approach to enhance impact of research for development. *Agricultural Systems* 183: 102874. DOI: 10.1016/j.agsy.2020.102874

Schut M, Klerkx L, Sartas M, Lamers D, Campbell MM, Ogbonna I, Kaushik P, Atta-Krah K, Leeuwis C. 2016. Innovation platforms: Experiences with their institutional embedding in agricultural research for development. *Experimental Agriculture* 52: 537–561. DOI: 10.1017/S001447971500023X

Schut M, Leeuwis C, Thiele G. 2020. Science of Scaling: Understanding and guiding the scaling of innovation for societal outcomes. *Agricultural Systems* 184. DOI: 10.1016/j.agsy.2020.102908

Sumberg J. 2005. Constraints to the adoption of agricultural innovations: Is it time for a re-think? *Outlook on Agriculture* 34: 7–10. DOI: 10.5367/0000000053295141

Sumberg J. 2017. *Agronomy for development: The politics of knowledge in agricultural research*. Routledge: Abingdon, Oxon. DOI: 10.4324/9781315284057

Sumberg J, Irving R, Adams E, Thompson J. 2012. Success-making and success stories: Agronomic research in the spotlight. In: Sumberg J and Thompson J (eds) *Contested Agronomy: Agricultural Research in a Changing World*. Routledge: Abingdon, Oxon, 186–203. DOI: 10.4324/9780203125434

Thierfelder C, Bunderson WT, Jere ZD, Mutenje M, Ngwira AR. 2016. Development of Conservation Agriculture (CA) Systems in Malawi: Lessons Learned From 2005 To 2014. *Experimental Agriculture* 52: 579–604. DOI: 10.1017/S0014479715000265

Thierfelder C, Chisui JL, Gama M, Cheesman S, Jere ZD, Trent Bunderson W, Eash NS, Rusinamhodzi L. 2013. Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. *Field Crops Research* 142: 47–57. DOI: 10.1016/j.fcr.2012.11.010

Thierfelder C, Rusinamhodzi L, Ngwira AR, Mupangwa W, Nyagumbo I, Kassie GT, Cairns JE. 2015. Conservation agriculture in Southern Africa: Advances in knowledge. *Renewable Agriculture and Food Systems* 30: 328–348. DOI: 10.1017/S1742170513000550

Thompson J, Scoones I. 1994. Challenging the populist perspective: Rural people's knowledge, agricultural research, and extension practice. *Agriculture and Human Values* 11: 58–76. DOI: 10.1007/BF01530446

Ward PS, Bell AR, Droppelmann K, Benton TG. 2018. Early adoption of conservation agriculture practices: Understanding partial compliance in programs with multiple adoption decisions. *Land Use Policy* 70: 27–37. DOI: 10.1016/j.landusepol.2017.10.001

Whitfield S. 2015. *Adapting to Climate Uncertainty in African Agriculture: Narratives and Knowledge Politics.* Earthscan, Routledge: Abingdon, Oxon. DOI: 10.4324/9781315725680

Whitfield S, Dougill AJ, Dyer JC, Kalaba FK, Leventon J, Stringer LC. 2015. Critical reflection on knowledge and narratives of conservation agriculture. *Geoforum* 60: 133–142. DOI: 10.1016/j.geoforum.2015.01.016

Whitfield S, Marshall A. 2017. Defining and delivering "sustainable" agriculture in the UK after Brexit: interdisciplinary lessons from experiences of agricultural reform. *International Journal of Agricultural Sustainability* 15: 501–513. DOI: 10.1080/14735903.2017.1337837

Wigboldus S, Klerkx L, Leeuwis C, Schut M, Muilerman S, Jochemsen H. 2016. Systemic perspectives on scaling agricultural innovations. A review. *Agronomy for Sustainable Development* 36: 1–20. DOI: 10.1007/s13593-016-0380-z

Zanello G, Fu X, Mohnen P, Ventresca M. 2016. the Creation and Diffusion of Innovation in Developing Countries: a Systematic Literature Review. *Journal of Economic Surveys* 30: 884–912. DOI: 10.1111/joes.12126

Chapter 5

Discussion and Conclusion

This thesis set out to address the following two objectives, as outlined in Chapter 1:

Objective 1) To critically evaluate the role of knowledge and associated small holder farmer decision-making in the process of agricultural innovation for development in Malawi

O**bjective 2)** To reflect on the learning opportunities, contributions and challenges of interdisciplinarity in the context of agricultural innovation and farmer decision-making.

Through a case study of Conservation Agriculture in Malawi, the empirical work presented in the dissertation contributes to enhancing understanding of the processes of agricultural innovation. It has a focus on how knowledge is shared and communicated between the actors involved at different scales in the design, delivery, adoption and adaptation of agricultural technologies. By reflecting on my own role and positionality as a critical researcher and knowledge broker within the innovation landscape, I also add to the understandings of the technical, social and political dimensions of knowledge creation and sharing in this context.

Section 5.1 presents an integrated discussion of the empirical insights from the Malawian case studies presented in Chapters 2, 3 and 4 and how they contribute holistically to the critical understanding of innovation processes. Here, I particularly focus on how knowledge is constructed in technical, social and political ways within the context of agricultural innovation, and the implications of this knowledge construction for the adoption and adaptation of conservation agriculture practices. Objective 2 is discussed in section 5.2 reflecting on the interdisciplinary and participatory methodological approach adopted. Throughout this section, I include reflections on my personal experience of pursuing an interdisciplinary approach and collaborations, which provides broader lessons for using such approach in agricultural development research.

5.1 How agricultural innovation processes happen within the innovation landscape

5.1.1 Technical construction of knowledge in the innovation landscape

As Chapter 2 shows, the technical construction of knowledge plays an important role within the innovation landscape. There is significant effort across the research community in creating and improving a technical knowledge base through controlled agronomic experimentation and technical metrics of performance (Mhlanga, 2021; Steward *et al.*, 2018; Thierfelder *et al.*, 2016). This is an ongoing technical construction of knowledge that involves building evidence on the performance of CA through natural science based methods and protocols, including experimental trials. Technical construction of knowledge in this research takes place through the collection of biophysical and chemical evidence of CA performance, as well as through the use of farm trials designed for technical evidence building and communication.

Underpinned by this technically constructed evidence base, the impact of CA on soil health represents one of its most heralded, but also contested, benefits (e.g. Andersson & D'Souza, 2014; Giller *et al.*, 2009). As we might expect, collectively the evidence that has emerged from across research station and on-farm trial experiments does not offer a uniform and conclusive picture of the relationship between CA practice and soil health (Baudron *et al.*, 2011; Cheesman *et al.*, 2016; Ligowe *et al.*, 2017; Mloza-Banda *et al.*, 2016).

In the empirical work that I present on integrated soil health assessment in Chapter 3, I focus on the benefits and challenges of integrating conventional scientific and farmers' local knowledges within the technical construction of knowledge. This work involved conducting integrated soil health evaluations of CA impacts at on-farm trials. The resulting measurements produced a technical evidence base that supports the argument that CA can improve soil structure, moisture, yield and infiltration. CA performed better compared to conventional practice on sandy soils and in drier conditions, showing the importance of climate and soil conditions (Pittelkow *et al.*, 2014; Steward *et al.*, 2018). The integration helped to triangulate observations and metrics (e.g., higher exchangeable ammonium, nitrate and nitrite values under CA) and offer insight into some of the soil processes and mechanisms that CA affects.

Farmers' perspectives and interpretations of CA impacts on infiltration and soil erosion were seemingly inconsistent. There were also discrepancies between the dominant scientific narrative around no-tillage (which is supported by evidence of the long-term build-up of nitrogen and yield measurements under CA) and farmers' perspectives on ridge making. Farmers' perceived ridge making as redistributing nutrients and aerating the soil, and this knowledge contributes to the continued popularity of ridges. However, the empirical work on innovation processes presented in the thesis indicates that this technically constructed knowledge does not translate simply into decision making within Malawian farm systems.

As an observer, I was interested in critically evaluating how evidence is produced and communicated within the on-farm trials set-up by CIMMYT, which themselves have a technical design and purpose. The ‘expert’ scientific knowledge generated from, and presented through, on-farm trials was highly respected among farmers. The trials provided a means for farmers to observe and engage with the technical construction of knowledge, and offered a persuasive evidence base for farmers considering adopting those practices. However, the on-farm trials were perceived as ‘unrealistic’, as the case studies in Chapter 4 demonstrated, due to the perceived resource and knowledge support requirements.

The case studies in Chapter 4 revealed that some farmers expressed not having the 'courage' to try new practices because they do not have access to resources, training or ongoing technical support. In some cases the complexity of trials also represented a barrier to uptake and CA upscaling. The on-farm trials comprised various maize varieties, precision planting techniques (that involved the use of tools to measure exact plant station distances), and Sasakawa planting in addition to the CA practices. On-farm trials, by nature of their complexity can become difficult to interpret by anyone outside of this scientific community and can quickly become written off by farmers as being overly-technical or not realistic. This is contrary to the intention that on-farm trials should offer a convincing evidence base for, and motivate, behaviour change. Based on the powercube framework by Gaventa (2006) on-farm demonstration trials are an invited space, where farmers are invited to participate in a pre-designed setting. The communication barrier suggests that on-farm trials alone will not be sufficient to facilitate learning and co-construction of technical knowledges. Additional interaction between innovation developers, extension support and farmers is needed to provide better insight into the innovation learning and knowledge construction across the innovation landscape.

5.1.2 Social construction of knowledge in the innovation landscape

The empirical chapters of this thesis contribute to the argument that farmer decision-making is shaped by both social and agro-ecological context. As the case studies in Chapter 4 show, there is a large range of interacting factors that shape decision-making around the use and adaptation of CA practices including agro-ecology, health, labour, economics, resource endowment, family size, age, gender, experience, risk aversity, alternative practices available, historical experiences and social dynamics. Recognition of the complex ways in which knowledge is socially constructed, challenges the idea that longer exposure to innovation leads to increased ‘adoption’ (Cheesman *et al.*, 2017). The integrated learning approach in Chapter 3 illustrated how local observations and beliefs interact with scientific evidence and observations, leading to nuanced and dynamic farm system decision-making. Further, it is evident in Chapter 4 that farmers’ learning takes places across knowledges and through dynamic processes.

In Chapter 2 we see that in academic literature, the question of 'what forms of Conservation Agriculture work, where, and why?' is addressed through distinct and siloed agro-ecological and socio-economic disciplines. This implies that the dynamic nature of farm level decision making is not adequately reflected in the current norms and institutionalised approaches of the agriculture and development research communities. The mismatch in the way knowledge construction takes place in the different contexts, namely the farm system and the Research and Development contexts, results in knowledge gaps in understanding innovation processes.

In particular the use of 'adoption' as a metric of success within research on CA represents a particular disconnect between research and the realities of the farmer and the farming system. Adoption rates are a quantitative indicator used to underpin success stories around CA, but this does not reflect the nuanced and dynamic innovation processes that farmers engage in. In farm systems there is a changing mosaic of agricultural practices over space and time. These dynamic changes over space and time are evident throughout the thesis, for example in, the development of the Sasakawa definition of CA used in farm systems (i.e. as an innovative step towards the perceived CA package but without removing ridges) (Chapter 4), the experimentation with practices, such as the 'three-year system' by Mary (i.e. one year ridges and no ridges for two years) (Chapter 4, Section 4.3.5), or the adaptation of practices to soil 'hardness' or to the communication of weather forecasts (Chapters 3 and 4). Dynamic farm system processes show both the scaling of practices, such as residues use in ridges as evidenced in Chapter 4, and unbundling or removing of the practices due to other contextual factors such as health costs or heavy rainfall as evidenced in Chapter 3.

The contextualised nature of farm decision making was evident in the cases presented in Chapter 4 in which farmers adapted CA practices because of the resource costs associated with no-till or because of social pressure (e.g., comments of being 'lazy' for not making ridges, and the acceptance of 0.1ha as a CA trial plot). In some cases, where no-till costs were too high, the hybrid practice that resulted was, for example, burying residues in ridges. The hybridised knowledges and practices that are socially constructed within the farm system context are much less predictable than ideas of linear diffusion of innovation (Rogers, 2003) suggest.

In the process of interacting knowledges, the on-farm trials, extension officers and lead farmers play a crucial role as knowledge brokers. Interacting with the farmers around on-farm trials helped to unpack the perception that new practices should be implemented as demonstrated. This is contrary to the adaptation and contextualisation taking place as described in the previous paragraphs, but this perception of direct implementation as demonstrated concerned the needed pre-conditions. Examples of these conditions include farmer practices focused on only no-tillage if there are sufficient residues, the need for hybrid seed varieties, fertilizers, or the access to the perceived level of residues. Few lead farmers mentioned receiving instructions about how to apply CA practices outside the trial on own land or expressed uncertainty about the reasoning behind practices on the trial. This implies a disconnect between the farmers and the trial in terms of ownership and involvement, as also reported in Brown et al. (2020). Drawing from these examples, observations of how practices 'look' and 'how to do them' is the dominant knowledge farmers take from on-farm trials, as opposed to interactive 'why to do practices' type of knowledge embedded in capacity building for agricultural development. The 'why' knowledge and evidence building for CA impact on soil health as recorded in scientific literature (explored in Chapter 2) are therefore not directly transferred as evidence for implementation in the Malawian farm system. Within the powercube framework for social spaces (Gaventa, 2016), on-farm demonstration trials are an invited space where farmers participate, but only have a small role in defining and shaping that space. This suggests that the on-farm trial, as an interaction tool, provides limited opportunity for farmers to engage in useful co-production of locally-relevant knowledge.

In overcoming these challenges, the role of knowledge brokers in facilitating learning and improving insights across social contexts is crucial. The existing knowledge brokers identified in this research case study are the agricultural extension officers, and to a lesser extent the lead farmers. These individuals, have become gatekeepers of agricultural innovation knowledge (King *et al.*, 2019; Klerkx *et al.*, 2009, 2010) and are in charge of overseeing on-farm trials. In this capacity, knowledge brokers were connected to the agricultural innovation promotors (e.g., CIMMYT and TLC), and sometimes perceived by other farmers as having personal stakes in the promotion of new innovations. This suggests an invisible power dynamic, which defines the meaning behind the use of the agricultural innovation. In both sites, the diffusion of innovation depended critically on the lead farmer but, as mentioned in Violet's case study (Chapter 4.3.6), information is not always distributed well by lead farmers. This can be due to limited insight of lead farmers into the agricultural technology, or their perceived lack of ownership of the trial activities as an invited space (despite it being on their land). On the other hand, a good reputation or trust built up with a knowledge broker can have a positive impact on practice implementation as demonstrated in the Mwansambo case study, in which there was an extension officer specifically allocated to support CA. The positive impact of this individual was associated with increased interactions between the extension officer and farmers capable of addressing specific farm system challenges and improved understanding amongst farmers of the mechanisms by which CA improves soil health in the local context.

Within the farm system, social configurations, especially interactions with knowledge brokers, determine the exposure that farmers have to new knowledge and evidence, for example farmers close to knowledge brokers will have more direct access to new information (e.g., benefits of residue retention). Such individuals may have direct access to evidence and knowledge through direct invitations to trials, and first-hand explanations by the agricultural extension officer or to field discussions with CIMMYT representatives. This research did not statistically prove a higher implementation of perceived CA practices among this group, but illustrated the important role of network building (referring to the configuration of people, innovation resources and environment) and social learning (referring to behaviour change at an individual level as influenced by collective change) (Leeuwis & Van den Ban, 2004).

Besides the social configurations, discussion between those with conflicting views and experiences played a major role in collective learning across the study communities. In Chapter 3 discrepancies were found between soil measurements and farmer observations, and also showed conflicting views within farmer observations on ridges, soil nutrients and hydraulics. The belief in residues being bad for groundnuts actively opposed the trial demonstration of groundnut under CA. These beliefs persist despite the recorded positive results for CA groundnuts (Bunderson *et al.*, 2017). Similarly, farmers were concerned about an apparent higher fertilizer need for Sasakawa CA planting (related to there being more planting stations) even though less fertilizer per plant station compared to conventional practice was recommended. Similarly, the often-stated residue retention challenges (Andersson & D'Souza, 2014; Giller *et al.*, 2009), were found to be based on different information sources (Chapter 4). If organisations such as CIMMYT do not actively engage in addressing these local beliefs, these narratives will continue to co-exist alongside contradictory evidence from the on-farm trials. Central to this engagement will be the cognitive and communication obstacles that currently limit the legitimacy of alternative knowledges and local experiences framed as being unscientific.

The social construction of an agricultural innovation knowledge landscape sketched out above shows dynamic farm system learning across knowledges involving various actors. Arguably, to achieve successful upscaling of technologies CIMMYT need to move away from a narrow technical construction of knowledge around agricultural innovation and engage more in processes of social learning, moving from interaction as an invited space to a increasingly claimed space. However, there is a politics behind the privileging of certain knowledges and knowledge processes over others. The following section, critically explores this politics of knowledge around agricultural innovation.

5.1.3 Politics of knowledge in the innovation landscape

There is a politics of knowledge which acts to determine what models and metrics of agricultural innovation predominate. The role of the on-farm trials as a tool in scaling is place-based but highly orchestrated by the institutional discourse. In the case study contexts of this research, long-term donor funding for the farm trials (which are more than 10 years old) has been challenging. As donors, and donor driven agendas have changed, so too has the design of these trials in response. The need for donor support puts pressure on an organisation like CIMMYT to build evidence and 'success' stories to make a case for future funding applications. The innovation drivers, who influence the innovation presented on-farm trials, are therefore diverse and multiple. In this case study, these include donors (currently GIZ, USAID), CIMMYT as a driver of the research in collaboration with the environmental NGO TLC and local government, who provide local organisation and extension officers.

An institutionalised 'impact-at-scale' agenda', which is compatible with reductionist theories of innovation diffusion and a pre-occupation with technology adoption rates, is consistent with the origins and history of the CGIAR remit and its wider conventional focus on technical solutions within agriculture for development (Leeuwis *et al.*, 2018). This focus is similarly evident in government programs, such as the Malawian government's Agricultural Input Programmes, Fertiliser Policy (Malawi Government Ministry of Agriculture, 2021) and its National Development Plan - Vision 2063 (National Planning Commission (NPC), 2020).

The evidence of a politics of knowledge in agricultural innovation is also apparent within farm system contexts. As argued previously in section 5.1.2, knowledge construction for agricultural innovation is influenced by group dynamics and identity. Lead farmers have an assumed power within this context by virtue of their designated role as teacher and their privileged access to knowledge and opportunities. They are the farmers 'invited' directly in the interaction space. The groups formed by lead farmers were identified as important for learning and sharing knowledge. On the other hand, farmers not within the lead farmers group identified the club mentality as a barrier to using CA practices, suggesting that "the trial farmers do it only because they get support and are the extension officer's farmers" (Section 4.3.6 Case 6: The 'female family caregiver'). This suggests an invisible power limiting the target of innovation as trial farmers who have 'access' and 'support'. These frictions created an 'access' hierarchy, in terms of knowledge and resources among farm systems, leading to inclusion and exclusion dynamics as described in the tyranny of participation by Cooke & Kothari (2001). Additionally, the perceived complexity of trials (e.g., "planting with a marked string looks complicated") leads to self-exclusion by non-trial farmers, creating invisible power through this psychological boundary of participation. To this end, the interventions created lower feelings of empowerment by farmers, raising the question of who is responsible for the conditions needed for agricultural change. One non-farm trial farmer mentioned that “peoples' mindsets are changing due to the trials” (Section 4.3.6). However, as demonstrated in these case studies, on-farm trials produce social dynamics which shape the innovation observation and experience of farmers.

Previous discussion between de Roo et al. (2019) and Wall et al. (2019) on the biases of demonstration trials and the impact on the validity of trial results focused on the technical conditions. However, this discussion did not expand on the on-farm demonstration trials as dynamic social interaction spaces shaping agricultural innovation. Analysing the technical, social and political construct of knowledge in the interaction space shows that on-farm demonstration trials (and associated knowledge brokers) fit within the institutional framework as a social space of interaction shaped by rules, norms and protocols. The formal rules are evidenced as scientific protocols, and organized interactions such as field days, but the informal (social and cultural) norms evidenced that demonstration trials instigate social dynamics among the farm systems and knowledge brokers, shaping agricultural innovation.

Further exploring this interaction space, the powercube framework (Gaventa, 2006) provides some additional insights. On-farm demonstration trials shape agricultural innovation from a closed space to an invited space, where farmers are invited to participate. However, this is on the terms of the institutional framing of interaction, mostly defined by the Research and Development context (e.g. technical evidence building, protocols and instructions). Within this space, there is hidden power in terms of who sets the agenda of the agricultural innovation, namely what practices are demonstrated. There is also invisible power shaping the meaning and social acceptability of new agricultural innovation. This defines what is feasible, for example if practices shown on demonstration trials are realistic and appropriate in the farm system context. The discussed framing of the interaction space represents a theoretical contribution to the agricultural innovation literature and has the potential to further explore agricultural innovation scaling as a process of knowledge construction. Having critically analysed the multifaceted knowledge construction for agricultural innovation, the next section discusses how this translates to defining ‘successful’ agricultural innovation across the innovation landscape.

5.1.4 Defining ‘successful’ agricultural innovation

The CA literature analysed in Chapter 2 showed that yield, soil health and adoption measurement are the most popular ways of measuring the impacts of CA. These quantitative and ‘binary’ measurements are convenient for monitoring and comparing progress, particularly in institutional contexts where impact-at-scale motivations predominate. By contrast, innovation as perceived by farmers is not only defined by its yield or adoption, but also by factors such as social dynamics (e.g., not making ridges perceived as lazy or beliefs that residues are bad for groundnut) and risk aversity (e.g., keeping options open with ridges for costs later in the season) (Fisher *et al.*, 2018; Holden *et al.*, 2018; Khataza *et al.*, 2018). Besides these intangible factors, the empirical work in Chapter 4 has shown that the contextual farm system cost and benefit balance (section 4.4.2) is the main determinant of 'success'. Here contextual cost and benefit is not only a financial or rational balance, it includes various factors, timings, and priorities, such as health, labour, seasonal weather, resources, additional livelihood strategies and other available agricultural practices. This is evident, for example, in some farmers' preferences for adding residues in ridges and avoiding the costs associated with no-tillage. Success is viewed locally as dependent on the agricultural technology's fit within the farm system livelihood context, objectives, goals and the relative improvement from already used practices, shaping agricultural innovation in a 'claimed' space.

Farmers adapt or change agricultural practices according to what suits during that particular time. For example, residue retention was found to be successful during a dry season, but conventional ridge-making practices were found to perform better during heavy rains. This dynamic ability to switch between or combine agricultural practices, thus adaptability, was for risk averse farmers defined as being successful. Similarly, conventional practices are perceived as leaving options open in case resources cannot be found later in the season, but residues as part of promoted CA practices were being added to conventional ridges. The hybridity and adaptation of agricultural practices as a changing mosaic over time and space, as opposed to the linear adoption of single technologies, is part of 'success' in farm systems

The above unpacked definition of 'successful' agricultural innovation, challenges the conventional bias towards reductionist indicators of technology adoption. The complexity and dynamics of agricultural innovation processes, including multiple knowledges, is incompatible with a theory of change that is based on linear diffusion. The alternative to this is a more complexity-aware theory of change (Douthwaite & Hoffecker, 2017), which outlines that technology implementation can be a goal, but should be accompanied by considering the effectiveness of the innovation process, and the building of capacity for development, innovation and adaptation. The following section critically reflects on the role of an interdisciplinary research approach in identifying these knowledge divergences within agricultural innovation.

5.2 Interdisciplinary approaches to studying agricultural innovation for development

Numerous studies have highlighted the benefits from interdisciplinary research to study complex real-world challenges (Lang *et al.*, 2012; Mauser *et al.*, 2013). Such approaches are especially valuable in contexts of uncertainty and conflicting evidence bases and narratives, as is typical of agricultural development research (e.g., Leach *et al.*, 2010; Whitfield, 2015). Interdisciplinary research can help to widen the evidence base around agricultural innovation scaling beyond that which comes from the agronomic sciences. As outlined in Chapter 1, the point of departure from an agronomic evaluation of CA in this thesis comes from its interdisciplinary approach - combining natural and social sciences, and participatory elements to evaluate understandings of technical, social and political constructions of knowledge across the agricultural innovation landscape in Malawi. In this section, I reflect on the contributions and challenges associated with adopting an interdisciplinary approach and argue that this has helped to bring to the fore more fundamental questions about what agricultural innovation for development is, and for whom, by whom, and how it is conceived and can be most usefully measured.

5.2.1 Learning across knowledges for agricultural innovation processes

Critically evaluating the CA literature in Chapter 2 revealed a particular emphasis on technical studies of the physical and agronomic properties of CA, narrow definitions of innovation and technology adoption, experimentation under controlled conditions and the use of quantitative metrics of soil health and yield data. This focus is underpinned by an epistemological and ontological orientation towards realism and objectivism. In contrast, there is relatively sparse literature on the social construction of knowledge and few studies that explored CA practices within farm system decision-making contexts. The identified distinctive clustering of conceptual and methodological approaches can be found in relation to research on other agricultural technologies, such as System of Rice Intensification (SRI) (Glover, 2011; Sumberg *et al.*, 2012). I argued that just reading across this technical and social literature is insufficient for understanding why CA does or does not work in under different contexts in Malawi. Although it is clear from this literature that there are multifaceted processes of adoption, adaptation and dis-adoption of CA, without interrogating the context-specific interactions of technically, socially and politically constructed knowledges, it is difficult to fully understand these processes.

Critically exploring conventional narratives of agricultural innovation contributes to the opening up of space for alternatives. Shifting the focus of attention within agricultural research for development from specific technologies towards contextualised processes of innovation can contribute to a more holistic evidence base around CA. For example, integrated soil learning in

Chapter 3, shows that opening up learning across knowledges can contribute to improved understandings of soil processes as well as farmer decision-making processes. This conceptual shift accounts for the wider system dynamics, stepwise adaptations, role of uncertainties and unknowns, or how learnings of CA are picked up in smallholder farming systems. The empirical thesis chapters have argued the need for opening up to multiple understandings of agricultural innovation and demonstrated ways of implementing this, such as integrated learning for soil health (Chapter 3) or qualitative approaches (Chapter 4).

An interdisciplinary approach involves acknowledging the multiple ways in which knowledge for agricultural innovation is constructed. Critical literature has outlined how institutional protocols and norms manifest in specific framings of problems, and particular approaches to measurement and analysis (Leeuwis & Van den Ban, 2004; Whitfield, 2015). As argued in Chapter 2, there is a predominance of technical framing of CA scaling, underpinned by quantitative metrics of success and narrow technical definitions of innovation. The bias towards technical measurements provides little understanding of the multiple drivers that shape agricultural innovation processes and create blindspots. Some of these blindspots were identified with the help of the interdisciplinary approach. This is evidenced in both Chapter 3 unpacking the nuance in decision-making (e.g., based on CA information adding residues in ridges or using old ridges) and Chapter 4 showing the diversity, complexity and dynamics in farmer decision-making (e.g., various CA adaptations, and changes of practices per season due to weather, labour or health).

The use of focus groups, individual interviews with rural appraisals, and technographic observation contributed to an understanding of the social and political construction of knowledge. This is in contrast to previous studies focusing on technology adoption constraints (Chinseu *et al.*, 2019; Ngwira *et al.*, 2014), or the agro-ecological research station assessments (Lark *et al.*, 2020; Ligowe *et al.*, 2017). In the working across qualitative and quantitative data for soil health evaluation, some qualitative data was lost or reduced in meaning. For example, nuance in decision-making based on observations and context, such as farmers' soil health indicators subject to defining 'good' or 'bad' (e.g., plant and disease indicators). The need for quantification in the integrated soil health evaluation process made it challenging not to introduce a bias towards quantitative and reductionist metrics. Acknowledging these limits present in Chapter 3, supported the decision for a case study approach in Chapter 4 to provide more depth of insight into on-farm decision-making processes, beyond just quantitative analysis of the determinants of adoption.

For the quantitative analysis, soil measurements were taken on on-farm trials providing scientific rigour. They were measured *in situ* to link directly with farmers' observations and to include farmers in this process. This supported discussions on soil measurements, the role of different practices, engagement with the 'technical science' and reporting of results. *In situ* measuring did lead to losing some of the scientific rigour and accuracy that lab analysis can provide. However, the lab analysis for C, N and bulk density, was done out of community context. The contextualisation of soil results through the integrated soil health framework made results inappropriate for evidence building in different contexts. The generalisation of soil health results or adoption metrics is a goal for CA evidence building (Chapter 2), however, this implies a level of external validity is needed (Tobi & Kampen, 2018). Paradoxically, it is acknowledged that external validity for CA is challenging due to the wide variety in agro-ecological and socio-economic contexts. This highlights the importance of upscaling or institutionalizing a more inclusive process of evidence building, namely a stepwise integrated learning framework as presented in Chapter 3, to contribute to improved integrated understanding of CA performance.

Integration of disciplines also highlighted topics that are often underrepresented in single disciplinary approaches. For example, the ethics in soil science that comes with participation and sampling on-farm. Across the empirical work in this study, farmers shared concerns about the lack of sharing agro-ecological results from previous on-farm trial research. This created sceptical attitudes and decreased the feeling of involvement and ownership in the trials. Drawing from learnings in the social sciences, which is more sensitive to ethical issues related to humans (Tobi & Kampen, 2018), can reveal the real-world implications of technical soil health research. From this agronomic research perspective, following protocols and norms is crucial for the 'credibility' of the results and this is often questioned in other disciplinary approaches such as farmer participation (Lang *et al.*, 2012). However, the empirical chapters show that these technical approaches risk losing 'salience' (i.e. relevance of the results) as perceived by farmers or other implementing stakeholders (Lang *et al.*, 2012). This demonstrates the relevance of interdisciplinary work to reintegrate science within society.

Box 2. Self-reflection on the interdisciplinary approach

By integrating and learning across disciplines, I attempted to validate the results, but quickly discovered that the disciplines did not integrate easily. I had to let go of rigidity and pre-conception in my research questions, and realise that they were not necessarily going to 'solve the problem of CA adoption', despite some stakeholders expressing it as such. Eventually I realized the interdisciplinary process was what was missing from CA and agricultural innovation literature. This process became especially prominent through working with researchers from social and natural sciences, the structuring and interpretation of results, and reviewer feedback (e.g., the comments that local knowledge has no value in soil science). Furthermore, an open approach enabled me to quickly adapt to the challenges of Cyclone Idai and floods during my fieldwork. These events made me consider that farmers' approaches cannot be captured in the technical constraint adoption framework, since resilience is a dynamic process. From the perspective as an outsider with an interdisciplinary background, the focus on processes and approaches in agricultural innovation seemed fitting and made reflection on the methodological approaches more important.

Through applying an interdisciplinary approach, I became aware of the assumptions, language and protocols used by colleagues in their respective disciplines and institutions. Seeing this unfold in meetings, and in the field, I positioned myself as a mediator. Through collaboration I learnt that interdisciplinary and participatory approaches are often called for, but can end up symbolic due to challenges in implementation. Discussion about what data really represents made me realize that political agendas influence data presentation, either in favour of or against CA. Throughout my PhD I found the dynamics between authors, reviews and publications was embedded in a wider political landscape. This created a constant search for balance and reflection including the management of expectations, priorities and defining success. It led me to question if the mediating and trying to get various perspectives included resulted in leaving out storylines. For example, drawing from critical social sciences, academic and contested agronomy perspective, I developed a leaning towards a critical look at the CA narrative, but consciously chose to be constructive in this criticism from an understanding that the practical implementation has challenges and uncertainties. Navigating this space has become one of my steepest learning curves.

5.2.2 Reflections on the positionality, 'participation', and project relations

In this research, there was a need to discuss the farm system experience to gain a broader understanding of social and political agricultural innovation processes. Participatory approaches, promoted as giving a voice to local experience, have been a long contested topic in agricultural development (e.g., Chambers, 1983; Cooke & Kothari, 2001). Critiques question the power relations' caused by, or hidden within, participatory approaches, and the extent to which local experiences are represented (Cooke & Kothari, 2001). These fallacies include group dynamics leading to socially acceptable answers, and the potential for enforcing existing community power dynamics (Cooke & Kothari, 2001). Reflection on these challenges of participation led me to take a more individualised approach to farmer interviews. These helped to mitigate some of the challenges of group dynamics, participation tyranny, and my positionality as an outsider within the context of CA promotion by collaborators.

Throughout this research, I recognized that there is no dualism in knowledge between scientific and local knowledges: types of knowledge do not exist in isolation of each other, but rather they interact throughout (Briggs & Moyo, 2012; Stringer & Reed, 2007). Similarly, local knowledge does not need to fit within the scientific knowledge framing and standards or vice versa. My role, however, was dualistic: I became an observer of knowledge processes but also a facilitator (e.g., knowledge broker), being aware of my own background in scientific and western education. The role of observer is based on my own interpretation of answers and activities as they would take place without my involvement, namely the decision-making on agricultural practices over time as discussed in Section 5.1. This role is not necessarily distinct from the facilitator role, since to an extent my position within the innovation landscape affects what I observed. The role of facilitator did have a more distinctive effect on the knowledge construction. It was apparent that my connection with CIMMYT, and the set research context of CA and soil analysis on-farm trials created expectations and feedback by stakeholders (Box 2 & 3). It also set limitations in the research design due to my limited ability to influence the CIMMYT trial design.

My institutional ties were expressed in the context of working and exchanging knowledge on existing on-farm trials promoted by CIMMYT, Total LandCare and local government. The 10-year-old CIMMYT on-farm trials provided a recognizable, lasting and sustainable basis for interaction with farmers, and a way to ensure results would be returned to stakeholders. It is important to note that my research design with participatory elements did not redefine relationships between the community and CIMMYT, as often heralded within participatory approaches (Cooke & Kothari, 2001). In reflection, the research mostly showed how farmer ‘participation’ in the on-farm trial and lead farmers system create social dynamics and grouping as discussed in section 5.1.3.

On a scale of existing participation frameworks, there was mainly a consultative role (Biggs, 1989), but with the soil health research design there was a move towards collaborative partnership between researcher and farmer (Biggs, 1989). However, participation in this research was limited by the on-farm trial design and set research context. The on-farm trial design was controlled by researchers, and farmers maintained the trial with assistance and instruction from the extension officer. Participatory elements were therefore present in sampling and interpretation but generally absent in the research design. Within the research design a more open approach for questions and methodologies was taken, but boundaries were defined by topics of evaluating soil health results on CA on-farm trials. Reflecting on this work in relation to the emerging citizen science, greater depth of participation and partnership could have been enabled through farmer inclusion in the research design, defining goals, needs and in a larger extent the agricultural innovation.

The learning on contextualisation of research data and local experience, including understanding context and language, were for me (as an outsider) restricted. The research assistants were Malawian but were also outsiders to the study communities. The translation of conversations to English will have contributed to loss of nuance and meaning of the experience. Conversations were recorded to cross check all interview notes and apply triangulation. There was a reliance on triangulation across the interviews, focus groups, soil health framework, and technographic observation to decrease the bias and loss of meaning, but as outsider this is unavoidable (Griffiths, 2017). The ability to communicate in iterative cycles of fieldwork and through practice (not only verbal language) with soil sampling improved the sharing and communication of experiences, and addressed farmers concerns on soil science health evaluations based within technical and 'scientific' epistemic. Unfortunately, Covid-19 did prevent me from going back to the area another time to present and reflect on final findings, and to discuss the practical implications. The iterative and interdisciplinary approach provided a wider evidence base, changed the conversation to a two-way interest in soil health learning, and can contribute to the need to address 'helicopter research' (i.e. when external researchers come in and take and analyse samples without local involvement or acknowledgement) concerns in soil science (Giller, 2020; Minasny *et al.*, 2020).

Box 3. Self-reflection on project relations

The awareness of the CA agenda, on the part of farmers, around the trials meant that there were initial expectations about my research agenda and promotion of CA. At the start, there was a strong tendency to say how good CA was, with some emphasis on the resource challenges. Furthermore, trying to defy the presumed role of previous researchers or innovation promotors acting like 'teachers' or 'extracting' was challenging. Changing these expectations and relations took time, and I managed by repeatedly emphasizing that my role is independent of CIMMYT and CA promotion, unlearning and questioning my preconceptions, along with interactions in the local area to have more candid and informal conversations. Another aspect was my status as a young, student and unmarried female, which in participation of some daily activities, created more informal interaction. Of course, positionality and long-lasting institutional relations remain dominant factors creating power dynamics, and preconceived ideas. Although aware of this, there remained an undeniable effect on the research and relations. In a similar fashion, reflection on position and role of myself as a researcher continues to develop.

Box 3. Self-reflection on project relations (continued)

The idea for the soil sampling framework was born from realizing that learning across knowledges is more than just disciplinary perspectives and that natural science research on the trials remained separate from the farm systems. However, as the attempt to increase participation and farm system understanding continued, I realized, as an outsider, I have no place to delve deep into 'local experience'. After interacting with social sciences as part of the interdisciplinary process, I concluded I will always be limited in my ability to interpret, understand and represent the farmers. In particular, critically reflecting on the concept of participation made me realize that participation is limited once the research design is already set. What was possible was a sharing of results and reflections, supporting an increase in the 'science' participation and discussion. COVID-19 led to the cancellation of another iteration of data sharing and feedback, which also limited the farm system feedback. Keeping an open approach was the smallest way I felt I could keep this element alive; at least, to the extent I was able in my position.

In hindsight, I came to think of my approach as interdisciplinary with participatory elements. Within this process of reflection and learning, I felt limited agency to change activities or approaches and questioned my role as a student and outsider in that. The focus was therefore on changes I could influence, such as iterations, feedback loops between stakeholders, and a focus on more open narrative approaches including more flexibility in defining agricultural innovation. I would have liked more local involvement in the design and feedback, including as authors on my papers, to further address helicopter science (Giller, 2020; Minasny et al., 2020).This is highly needed in the this field and needs to be more widely discussed. However, the involvement in an existing 10-year trial programme brought with it value of feeding into lasting relations and projects.

5.3 Implications for scaling agricultural innovation

The main contributions of this thesis are threefold: 1) employing and evaluating an interdisciplinary research approach to addressing knowledge gaps on CA scaling, 2) providing in depth contextual empirical case study insights into CA innovation and farm trial dynamics within Malawi, and 3) evaluating the instrumental role of on-farm trials as interaction spaces of (constructed) knowledges in innovation scaling. Given the various actors and institutes involved across the innovation landscape, there are multiple interconnected findings and practical implications to be drawn. Whereas most empirical insights from this thesis create a better understanding of knowledge construction for agricultural innovation in farm systems, most of the practical implications concern the set-up, pre conditions and evaluations of agricultural innovation processes driven by the Research and Development context, in which CA and climate-smart agriculture interventions more broadly are situated.

In conceiving of agricultural innovation, dominant technocentric approaches do not reflect the complex and often fluid realities of technology adaptation and application on farms. This underpins the apparent paradox of 'low adoption' (Kassam *et al.*, 2019) and the losing track of innovation as being a means to end, namely improving farmers' resilience and livelihood (Lipper *et al.*, 2018). The outlined social constructivist nature of agricultural innovation unpacks innovation processes in farm systems as dynamic, diverse and multi-dimensional. Without acknowledging these underlying challenges, interventions will be limited in their impact and connection to farm systems. To this end, social constructivist scholarship such as provided in this integrated study of CA can provide a suitable point of departure for learning across knowledges and widening the interaction space for agricultural innovation development, which will improve scaling processes.

This research has argued that agricultural innovation should not be conceived of as fixed technological packages. Various technologies can scale together (e.g., new maize varieties, CA, agroforestry and herbicides) or lead to replacing of other technologies (e.g., current maize varieties) (Kilelu *et al.*, 2013; Sartas *et al.*, 2020; Wigboldus *et al.*, 2016). When aiming to scale practices, organisations such as CIMMYT need to consider these connections between technologies. Accordingly, narrow definitions on technology packages and understanding of scaling processes need to become more flexible, allowing local experimentation and adaptations, moving from closed and invited interaction spaces to more claimed spaces. For researchers, this suggests a more open approach to defining and evaluating agricultural innovation and its success. The wider conceptualisation of innovation provides the opportunity for innovation drivers to re-engage with farmers' intrinsic motivation to adapt practices and experiment, as opposed to them being engaged with purely as receivers of innovation.

Equally, shifting the focus from specific package promotion to the dynamic processes and quality of scaling enables agricultural development agencies to move away from being tied to their particular solutions. The current institutional structures of donors and development as business reinforces the motivation that organisations have to prove the importance and success stories of their specific technologies. With pressure for success reporting unintended impacts or unknown outcomes in farm systems are often missed. A focus on the quality of the process of scaling supports the framing of 'responsible scaling' (Woltering *et al.*, 2019). This acknowledges that scaling has unintended impacts in farm systems with unknown outcomes. An example of unknown outcomes is the diversity in the use of CA information in relation to farm practice implementation (Chapter 4). This considers agricultural decision-making as part of livelihoods, (e.g., monitoring and evaluating qualitative data on this equally), and the role of innovation in society, as is underlined in this thesis's focus on interdisciplinary and multi-dimensional knowledge approach.

In this described shift, the role of agricultural development agencies becomes one of process facilitators towards scaling as system change. An example attempting this, with an approach focused on farmer and extension services engagement and social learning, is the 'Plan Intégre du Paysan' (PIP) approach applied in Burundi (Kessler *et al.*, 2020, 2016). The starting point is the creation of vision and action plans at household level, based on (intrinsic) motivation, stewardship and resilience (adaptability to conditions). The training is focused on the wider integrated farm planning and skills, which includes technical knowledge on conservation practices (e.g., intercropping, mulching, adequate crop spacing, rotations, vegetable garden, contour line ploughing). The integrated multi-scale approach across all project stages defines 'integrated' as "to bridging production, environmental, and well-being goals, based on participatory processes and multi-stakeholder learning" (Kessler *et al.*, 2020: 5), including stakeholders, institutions, environmental and developmental factors. The manner of distribution is similar as to CIMMYT's approach in terms of farmer-to-farmer knowledge sharing based on positive experience, however the approach to the type of knowledge (not trial based, but a multitude of farm household skills for attitude change (Kessler *et al.*, 2016)) and farm system input in the design of changes is different. Alternatively, exploring already existing local conservation practices and initiatives could provide another point of departure for scaling sustainable agricultural practice, building on farmers' ability and confidence to experiment with new knowledge, or to reconnect with old practices (e.g., CA practices are similar to old practices) (e.g., Briggs & Moyo, 2012; Moyo, 2009) .

Redefining the nature of agricultural innovation has implications for the evaluation and monitoring of scaling 'success' by the agricultural research and development community. As evidenced across the empirical chapters, quantitative indicators such as adoption do not adequately reflect the success of agricultural innovation processes. As Chapter 2 illustrated, socio-economic indicators and studies are often highly contextualised and lack systematic, replicable documentation of agronomic conditions, practices and success metrics. However, the controlled conditions and strictly defined practices of agro-ecological studies miss out on the dynamic and complex realities in farm systems. This contrast means it is difficult to have compatible data and metrics across these studies and integrate across the identified clusters to build a more complete picture of agricultural innovation 'success'. Better provision of meta-data by research studies, accessible databases at central points such the CGIAR and FAO, impact evaluations in terms of farmer resilience metrics, and participatory and interdisciplinary evaluations, as implemented in Chapter 3, can provide more holistic evaluation, and more suitable alternatives to adoption metrics.

Acknowledging the dynamic nature of agricultural innovation comes with challenges for innovation scaling, such as allowing for non-linear learning processes. Scaling should be perceived as a system transformation including technical, natural, political and social elements and contexts. This system transformation requires navigating the multiple levels and disciplines, understanding what knowledges can contribute to or not, and how different actors can collaborate and support each other (Woltering *et al.*, 2019). It requires reflection on the influence of historical innovation scaling narratives including the business model for innovation embedded in neoliberalism and the dominance of western knowledge. Changes within specific projects or interventions require structural changes the wider political and donor driven system (e.g., business for development focus, success metrics, and timelines). These challenges can be addressed by improving transparency in the development of innovation, and communicating goals and needs across stakeholders.

Additionally, the soil health integrated assessment has demonstrated that there is value in the broader application of integrated learning and assessment. Here, the aim is not to upscale these integrated local learnings, but to facilitate technology downscaling (e.g., CA adaptation) and to understand the role of factors such as soil health within wider farmer decision-making. The co-generation of knowledge has the potential to create more just and representative knowledge engagement, ownership and trust relations, and open up pathways for alternative narratives and evidences. It should be associated with reflection and communication on the conditional assumptions and boundaries of knowledges. Defining these assumptions and boundaries provides clarity on the validity and legitimacy of these knowledges for agricultural innovation scaling in other contexts.

The suggested institutionalisation of integrated learning processes is strongly associated with feedback and iterations between farm systems and Research and Development context. These interactions are needed to unpack and comply with farm system dynamics, including unknowns, needs, uncertainties and emerging innovation challenges. The value of information is in its transfer and communication, and the interaction tools in ongoing two-way learning, such as on-farm trials and Farmer Field Schools. It is important to clarify the boundaries and limitations of these interaction tools for understanding the legitimacy of the knowledge and innovation. The challenge for the agricultural development community and implementation stakeholders, such as agricultural extension services, is to organize interventions and interactions in more flexible ways to enable the integration of various learning processes and knowledges. 'Participation' based learning across scientific and sectoral knowledges is a precondition for effective and responsible scaling to make the agricultural innovation relevant for real world context. Whereas there is a rich history of a 'participatory agenda' (Chambers, 1983; Chambers *et al.*, 1989), the popularity of linear diffusion and scaling for agricultural innovation has made 'participation' a tick box exercise, and claims participation freedom in invited spaces, without scrutinising its role in knowledge building and implementation. However, current scaling efforts and practice should not water down 'participation', but build on it as a basis to develop collaborative and interdisciplinary pathways for agricultural innovation scaling to improve farmer resilience and livelihoods.

5.4 Conclusion

This thesis aimed to address two objectives: 1) to critically evaluate the role of knowledge and associated small holder farmer decision-making in the process of agricultural innovation for development in Malawi, and 2) to reflect on the learning opportunities, contributions and challenges of interdisciplinary research in the context of agricultural innovation and farmer decision-making. The three empirical chapters present in depth empirical insights on CA scaling in Malawi through on-farm trials, and critical evaluation of the instrumental role of on-farm trials in innovation scaling.

This research, presented in three papers as Chapter 2, 3 and 4, has offered an insight into the technical, social and political construction of knowledge in the agricultural innovation landscape through learning across scientific and sectoral knowledges. The CA case studies demonstrated a mismatch between knowledge construction in the techno-scientific, Research and Development context and the dynamic and multi-dimensional farm system agricultural innovation processes, including small holder decision-making. The impact at scale pressure within the research and development community has contributed to a focus on technical innovation approaches and success stories supported by quantitative success metrics (e.g., adoption and agro-ecological indicators). However, the empirical insights showcase the fluidity, multi-dimensionality and adaptation of innovation in farm systems, evidencing that 'adoption' metrics and technical understanding of innovation are insufficient in representing farm system innovation processes.

The focus on the innovation landscape also unpacked a politics of knowledge around agricultural innovation scaling and the on-farm demonstration trial. Contributions were made to critical understandings of the instrumental role of this innovation landscape. On-farm trials and knowledge brokers have provided a valuable middle ground between contexts and knowledges, but are tools formed by, and that largely exist within, the dominant technical knowledge paradigm. This work's systematic and critical reflection on the nature of evidence building in CA, and its limitations and knowledge gaps is crucial in opening up space for alternative narratives and interaction. Increased learning and representation across knowledges can provide more understanding of scaling challenges, but requires barriers of interaction to be addressed and knowledge boundaries to be acknowledged.

The contribution of the thesis is that interdisciplinary approaches including multiple knowledges and social contexts are valuable for unpacking alternative narratives, nuances and dynamics in agricultural innovation processes. The research involved implemented approaches to understand the multiple perspectives on agricultural innovation through combining soil science and local experience on soil health (Chapter 3) and qualitative approaches going beyond 'adoption' metrics (Chapter 4). On critical reflection, there are methodological trade-offs based on disciplinary epistemological and ontological differences, and limitations in translating participants' understandings and framings. Learning and negotiating across knowledges emphasized the need for farmers' involvement in innovation processes to contextualize outcomes and facilitate the technology downscaling needed. Whereas 'participation' requires careful scrutinizing on its meaning, politics and positionality, as presented in this thesis, the empirical insights have shown that current scaling efforts should build on collaborative and interdisciplinary pathways for agricultural innovation scaling as a system change. Methodological recommendations included institutionalizing integrated learning across knowledges, widening the interactive innovation space, increasing iterative feedback loops, and reflection and communication on the conditional assumptions and boundaries of knowledges. Debates on CA (and broader CSA) across Malawi and sub-Saharan Africa need to focus on the dynamic process of innovation in farm systems, instead of solely perfecting a strict defined technology, and need to reframe 'success' in agricultural innovation to be farm system and farmer relevant.

References

Andersson JA, D'Souza S. 2014. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment* 187: 116–132. DOI: 10.1016/j.agee.2013.08.008

Baudron F, Tittonell P, Corbeels M, Letourmy P, Giller KE. 2011. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. *Field Crops Research* 132: 117–128. DOI: 10.1016/j.fcr.2011.09.008

Biggs SD. 1989. *Resource-Poor Farmer Participation in Research: A Synthesis of Experiences from Nine National Agricultural Research Systems*. The Hague, Netherlands

Briggs J, Moyo B. 2012. The Resilience of Indigenous Knowledge in Small-scale African Agriculture: Key Drivers. *Scottish Geographical Journal* 128: 64–80. DOI: 10.1080/14702541.2012.694703

Brown B, Nuberg I, Llewellyn R. 2020. From interest to implementation: exploring farmer progression of conservation agriculture in Eastern and Southern Africa. *Environment, Development and Sustainability* 22: 3159–3177. DOI: 10.1007/s10668-019-00340-5

Bunderson WT, Jere ZD, Thierfelder C, Gama M, Mwale BM, Ng'oma SWD, Museka RM, Paul JM, Mbale B, Mkandawire O, Tembo P. 2017. Implementing the Principles of Conservation Agriculture in Malawi: Crop Yields and Factors Affecting Adoption. In: Kassam AH, Mkomwa S and Friedrich T (eds) *Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate.* CABI: Wallingford, UK, 75–99

Chambers R. 1983. *Rural Development: Putting the Last First*. Longman Inc: New York

Chambers R, Pacey A, Thrupp LA. 1989. *Farmer First: Farmer Innovation and Agricultural Research*. Intermediate Technology Publications: London, UK

Cheesman S, Andersson JA, Frossard E. 2017. Does closing knowledge gaps close yield gaps? On-farm conservation agriculture trials and adoption dynamics in three smallholder farming areas in Zimbabwe. *Journal of Agricultural Science* 155: 81–100. DOI: 10.1017/S0021859616000095

Cheesman S, Thierfelder C, Eash NS, Kassie GT, Frossard E. 2016. Soil carbon stocks in conservation agriculture systems of Southern Africa. *Soil and Tillage Research* 156: 99–109. DOI: 10.1016/j.still.2015.09.018

Chinseu E, Dougill A, Stringer L. 2019. Why do smallholder farmers dis-adopt conservation agriculture? Insights from Malawi. *Land Degradation and Development* **30**: 533–543. DOI: 10.1002/ldr.3190

Cooke B, Kothari U. 2001. *Participation: the New Tyranny? International Journal of Educational Development.* Zed Books: London, UK

de Roo N, Andersson JA, Krupnik TJ. 2019. On-Farm Trials for Development Impact? The Organisation of Research and the Scaling of Agricultural Technologies. *Experimental Agriculture* **55**: 163–184. DOI: 10.1017/S0014479717000382

Douthwaite B, Hoffecker E. 2017. Towards a complexity-aware theory of change for participatory research programs working within agricultural innovation systems. *Agricultural Systems* 155: 88–102. DOI: 10.1016/j.agsy.2017.04.002

Fisher M, Holden ST, Thierfelder C, Katengeza SP. 2018. Awareness and adoption of conservation agriculture in Malawi: what difference can farmer-to-farmer extension make? *International Journal of Agricultural Sustainability* 16: 310–325. DOI: 10.1080/14735903.2018.1472411

Gaventa J. 2006. Finding the Spaces for Change: A Power Analysis. *IDS Bulletin* **37**: 23–33

Giller KE. 2020. Grounding the helicopters. *Geoderma* 373: 114302. DOI: 10.1016/j.geoderma.2020.114302

Giller KE, Witter E, Corbeels M, Tittonell P. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* 114: 23–34. DOI: 10.1016/j.fcr.2009.06.017

Glover D. 2011. The System of Rice Intensification: Time for an empirical turn. *NJAS - Wageningen Journal of Life Sciences* 57: 217–224. DOI: 10.1016/j.njas.2010.11.006

Griffiths M. 2017. From heterogeneous worlds: western privilege, class and positionality in the South. *Area* 49: 2–8. DOI: 10.1111/area.12277

Holden ST, Fisher M, Katengeza SP, Thierfelder C. 2018. Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land Use Policy* 76: 113–123. DOI: 10.1016/j.landusepol.2018.04.048

Kassam A, Friedrich T, Derpsch R. 2019. Global spread of Conservation Agriculture. International *Journal of Environmental Studies* 76: 29–51. DOI: 10.1080/00207233.2018.1494927

Kessler A, van Reemst L, Beun M, Slingerland E, Pol L, De Winne R. 2020. Mobilizing farmers to stop land degradation: A different discourse from Burundi. *Land Degradation and Development* 1–12. DOI: 10.1002/ldr.3763

Kessler CA, van Duivenbooden N, Nsabimana F, van Beek CL. 2016. Bringing ISFM to scale through an integrated farm planning approach: a case study from Burundi. *Nutrient Cycling in Agroecosystems* 105: 249–261. DOI: 10.1007/s10705-015-9708-3

Khataza RRB, Doole GJ, Kragt ME, Hailu A. 2018. Information acquisition, learning and the adoption of conservation agriculture in Malawi: A discrete-time duration analysis. *Technological Forecasting and Social Change* 132: 299–307. DOI: 10.1016/J.TECHFORE.2018.02.015

Kilelu CW, Klerkx L, Leeuwis C. 2013. Unravelling the role of innovation platforms in supporting co-evolution of innovation: Contributions and tensions in a smallholder dairy development programme. *Agricultural Systems* 118: 65–77. DOI: 10.1016/j.agsy.2013.03.003

King B, Fielke S, Bayne K, Klerkx L, Nettle R. 2019. Navigating shades of social capital and trust to leverage opportunities for rural innovation. *Journal of Rural Studies* 68: 123–134. DOI: 10.1016/j.jrurstud.2019.02.003

Klerkx L, Aarts N, Leeuwis C. 2010. Adaptive management in agricultural innovation systems: The interactions between innovation networks and their environment. *Agricultural Systems* 103: 390–400. DOI: 10.1016/j.agsy.2010.03.012

Klerkx L, Hall A, Leeuwis C. 2009. Strengthening agricultural innovation capacity: Are innovation brokers the answer? *International Journal of Agricultural Resources, Governance and Ecology* 8: 409–438. DOI: 10.1504/IJARGE.2009.032643

Lang DJ, Wiek A, Bergmann M, Stauffacher M, Martens P, Moll P, Swilling M, Thomas CJ. 2012. Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science* 7: 25–43. DOI: 10.1007/s11625-011-0149-x

Lark RM, Ligowe IS, Thierfelder C, Magwero N, Namaona W, Njira K. 2020. Longitudinal analysis of a long-term conservation agriculture experiment in Malawi and lessons for future experimental design. 1–22. DOI: 10.1017/S0014479720000125

Leach M, Scoones I, Stirling A. 2010. *Dynamic Sustainabilities: Technology, Environment, Social Justice.* Earthscan: Abingdon, Oxon

Leeuwis C, Schut M, Klerkx L. 2018. Systems Research in the CGIAR as an Arena of Struggle. In: Sumberg J (ed) *Agronomy for Development.* Routledge: Abingdon, Oxon, 59–78. DOI: 10.4324/9781315284057-5

Leeuwis C, Van den Ban A. 2004. *Communication for Rural Innovation Rethinking Agricultural Extension.* Blackwell Science Ltd: Oxford, UK. DOI: 10.1002/9780470995235

Ligowe IS, Cleoups Nalivata P, Njoloma J, Makumba W, Thierfelder C. 2017. Medium-term effects of conservation agriculture on soil quality. *African Journal of Agricultural Research* 12: 2412–2420. DOI: 10.5897/AJAR2016.11092

Lipper L, McCarthy N, Zilberman D, Asfaw S, Branca G. 2018. *Climate Smart Agriculture - Building Resilience to Climate Change.* Springer Nature: Cham, Switzerland. DOI: 10.1007/978-3-319-61194-5

Malawi Government Ministry of Agriculture. 2021. *National Fertiliser Policy.* Lilongwe, Malawi

Mauser W, Klepper G, Rice M, Schmalzbauer BS, Hackmann H, Leemans R, Moore H. 2013. *Transdisciplinary global change research: The co-creation of knowledge for sustainability. Current Opinion in Environmental Sustainability.* Elsevier, 420–431. DOI: 10.1016/j.cosust.2013.07.001

Mhlanga B, Mwila M, Thierfelder C. 2021. Improved nutrition and resilience will make conservation agriculture more attractive for Zambian smallholder farmers. *Renewable Agriculture and Food Systems* 1–14. DOI: 10.1017/S1742170521000065

Minasny B, Fiantis D, Mulyanto B, Sulaeman Y, Widyatmanti W. 2020. Global soil science research collaboration in the 21st century: Time to end helicopter research. *Geoderma* 373: 114299. DOI: 10.1016/j.geoderma.2020.114299

Mloza-Banda HR, Makwiza CN, Mloza-Banda ML. 2016. Soil properties after conversion to conservation agriculture from ridge tillage in Southern Malawi. *Journal of Arid Environments* 127: 7–16. DOI: 10.1016/j.jaridenv.2015.11.001

Moyo BHZ. 2009. Indigenous knowledge-based farming practices: A setting for the contestation of modernity, development and progress. *Scottish Geographical Journal* 125: 353–360. DOI: 10.1080/14702540903364385

National Planning Commission (NPC). 2020. *Malawi 2063 Malawi's Vision An Inclusively Wealthy and Self-reliant Nation*. Lilongwe, Malawi

Ngwira AR, Johnsen FH, Aune JB, Mekuria M, Thierfelder C. 2014. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. *Journal of Soil and Water Conservation* **69**: 107–119. DOI: 10.2489/jswc.69.2.107

Pittelkow CM, Liang X, Linquist BA, van Groenigen KJ, Lee J, Lundy ME, van Gestel N, Six J, Venterea RT, van Kessel C. 2014. Productivity limits and potentials of the principles of conservation agriculture. *Nature* 517: 365–368. DOI: 10.1038/nature13809

Rogers EM. 2003. *Diffusion of innovations*. The Free Press: New York, NY

Sartas M, Schut M, Proietti C, Thiele G, Leeuwis C. 2020. Scaling Readiness: Science and practice of an approach to enhance impact of research for development. *Agricultural Systems* 183: 102874. DOI: 10.1016/j.agsy.2020.102874

Steward PR, Dougill AJ, Thierfelder C, Pittelkow CM, Stringer LC, Kudzala M, Shackelford GE. 2018. The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments: A meta-regression of yields. *Agriculture, Ecosystems and Environment* 251: 194–202. DOI: 10.1016/j.agee.2017.09.019

Stringer LC, Reed MS. 2007. Land degradation assessment in southern Africa: Integrating local and scientific knowledge bases. *Land Degradation and Development* 18: 99–116. DOI: 10.1002/ldr.760

Sumberg J, Thompson J, Woodhouse P. 2012. *Contested Agronomy: Agricultural research in a changing world.* Earthscan, Routledge: Abingdon, Oxon

Thierfelder C, Matemba-Mutasa R, Bunderson WT, Mutenje M, Nyagumbo I, Mupangwa W. 2016. Evaluating manual conservation agriculture systems in southern Africa. *Agriculture, Ecosystems and Environment* 222: 112–124. DOI: 10.1016/j.agee.2016.02.009

Tobi H, Kampen JK. 2018. Research design: the methodology for interdisciplinary research framework. *Quality and Quantity* 52: 1209–1225. DOI: 10.1007/s11135-017-0513-8

Wall PC, Thierfelder CL, Nyagumbo I, Rusinamhodzi L, Mupangwa W. 2019. Comment on "De Roo et al. (2019). On-farm trials for development impact? the organization of research and the scaling of agricultural technologies." *Experimental Agriculture* **55**: 185–194. DOI: 10.1017/S0014479718000492

Whitfield S. 2015. *Adapting to Climate Uncertainty in African Agriculture: Narratives and Knowledge Politics*. Earthscan, Routledge: Abingdon, Oxon. DOI: 10.4324/9781315725680

Wigboldus S, Klerkx L, Leeuwis C, Schut M, Muilerman S, Jochemsen H. 2016. Systemic perspectives on scaling agricultural innovations. A review. *Agronomy for Sustainable Development* 36: 1–20. DOI: 10.1007/s13593-016-0380-z

Woltering L, Fehlenberg K, Gerard B, Ubels J, Cooley L. 2019. Scaling – from "reaching many" to sustainable systems change at scale: A critical shift in mindset. *Agricultural Systems* 176: 102652. DOI: 10.1016/j.agsy.2019.102652

Appendices

Appendix A: Ethics Clearance University of Leeds

The Secretariat
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UNIVERSITY OF LEEDS

Thirze Hermans
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ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee
University of Leeds

Dear Thirze

Title of study: **Conservation agriculture adoption in Malawi – interdisciplinary analysis of different knowledges**

Ethics reference: **AREA 17-147**

I am pleased to inform you that the above research application has been reviewed by the ESSL, Environment and LUBS (AREA) Faculty Research Ethics Committee and following receipt of your response to the Committee's initial comments, I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	Version	Date
AREA 17-147 Ethical_Review_Form_TH_AD.pdf	1	26/05/18
AREA 17-147 Participant_Information_Sheet_TH (I).doc	1	26/05/18
AREA 17-147 Participant_Information_Sheet_TH (FG).doc	1	26/05/18
AREA 17-147 Participant_consent_form_TH2.doc	1	26/05/18
AREA 17-147 Fieldwork_Assessment_Form_high_risk_general_TH.docx	1	26/05/18

Please notify the committee if you intend to make any amendments to the information in your ethics application as submitted at date of this approval as all changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation and other documents relating to the study, including any risk assessments. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator, the Secretariat
On behalf of Dr Kahryn Hughes, Chair, AREA Faculty Research Ethics Committee

Appendix B: Ethics Clearance LUANAR

VICE CHANCELLOR
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28th September 2018

Ms. Thirze Hermans

Sustainability Research Institute

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UK

Dear Ms. Hermans,

IRB APPROVAL FOR A PhD RESEARCH ON CONSERVATION AGRICULTURE ADOPTION IN MALAWI-INTERDISCPLINARY ANALYSIS OF DIFFERENT KNOWLEDGES

We at the Lilongwe University of Agriculture and Natural Resources (LUANAR), constituted an interim Internal Review Board (IRB) to review the PhD research on ***Conservation agriculture adoption in Malawi – interdisciplinary analysis of different knowledges***. We are pleased to inform you that the interim IRB unanimously approved the project.

Specifically, we confirm that:

1. The research instruments and the concept forms have been reviewed and that we find them sensitive to the local customs and rules; and
2. The research poses only minimal risk (the probability and the discomfort anticipated in the research are not greater than those ordinarily encountered in daily life).

It is with the above observation that I, on behalf of LUANAR, approve the PhD project on ***Conservation agriculture adoption in Malawi – interdisciplinary analysis of different knowledges***.

Lilongwe University of Agriculture and Natural Resources (LUANAR)
Dept of Environmental Sciences & Management
05 OCT 2018
P.O. Box 219
Lilongwe - Malawi

PP Limbikani Matumba, PhD
DIRECTOR OF RESEARCH AND OUTREACH

Appendix C: Supplementary Material to Chapter 3

C.1 On-farm trials management

All on-farm trials are managed by farmers with support from extension officers. For all treatments, ridge spacing was constant at 75cm between maize rows and 25cm between planting stations with one seed planted per station. In the maize-legume intercrop, pigeon pea (Lemu) and cowpea (Mwansambo) were planted between maize lines at 60cm and 40cm spacing respectively. All treatments received similar fertilizer application rates of 69 kg N ha^{-1}, which was applied in two stages: 100 kgha^{-1} of N:P:K (23:21:0+4S) during seeding and 100 kgha^{-1} of urea (46% N) approximately three weeks after crop emergence. Weeding is done manually with a hand hoe in the CP treatment at different times during the cropping season and ridges are reformed during this process (the operation is locally called "banking"). To control weeds in the CA treatments, a mixture of 2.5 L ha^{-1} glyphosate (N-(phos- phono-methyl) glycine), Harness® (acetochlor (2-ethyl-6-methylphenyl-d11)) (Mwansambo) or Bullet® (Lemu) (25.4% Alachlor (2-chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl) acetamide) and 14.5% atrazine (2-Chloro-4-ethylamino-6-isopropylamino-1,3,5-triazine)) was applied. Additional manual hoe weeding was advised as soon as weeds reached 10cm height or 10cm in circumference.

C.2 Focus groups & interviews themes

Below is the protocol that was followed for focus groups that were carried out in Lemu and Mwansambo, Malawi. Focus groups were conducted with the trial farmer group (6 farmers) and non-trial farmers (8-10 farmers). In total 6 focus groups discussion were conducted. The 38 semi-structured interviews followed up on the focus groups. These were conducted with 6 trial farmers in each community and a subsequent snowball methodology was used to select 12 non trial farmers in Mwansambo and 14 non trial farmers in Lemu.

Focus group discussion (FGD)

FGD started with an introduction, an explanation of what the goal and purpose of the discussion was and consent forms. Farmers were reminded that they are free to withdraw at any time.

Trial farmers FGD

1. Introductions and recalling of what practices are used on trial and own field.
2. Trial experience
    a. Time taken to be comfortable with new practices & process of learning
    b. Understanding of why practices are helpful and what the impact is of the practices.
3. Ranking of 3 practices on the trial *(Visual drawing)*
4. Discuss ranking trials
    a. Why is one practice more successful than the other?
    b. What indicators/observations are used to rank the practices?
    c. How are these indicators/observations used for assessment?
5. How important are these indicators?
    a. Discuss importance

Non-trial farmers FGD

1. Introductions and what practices are used on fields
2. What factors influence decision making on agricultural practices?
3. What observations are used to decide on agricultural practices?
4. How are these indicators/observations used for assessment (e.g., good or bad)?
5. How do the practices lead to these observations?

Interview themes guide

Interviews took place at a farmer's field and house. If appropriate for explanation and answer it took place while walking through the fields. The interview always started with an introduction, an explanation of what the goal and purpose of the interview was and consent form. Farmers were reminded that they are free to withdraw at any time.

1. Demographics
Family composition
Ages of family members
Education of family members
Household sources of income

2. Farming Activities & Decisions
What are current farming practices on field?
What are the current crops cultivated?
What is the size of land per crop?
Why are these practices preferred?

3.Mapping exercise *(Visual drawing)*
Mapping above practices and crops
What land is rented? Is labour hired?
Why were these practices chosen?

4.Timeline *(Visual drawing)*
Trial farmer
- When started trial?
- Did the trial change their own practices?
- Why did changes in practices occur?
- Why did they not expand or why did they expand their agricultural practices?

Non-trail farmer
- What changes have occurred in agricultural practices?
- When did the change occur?
- Why did this change occur?
- Why did they not expand or why did they expand their agricultural practices?

CA adoption challenges
- What are main challenges for them or others not to adopt CA?

If the topic of soil fertility already occurred in the above questions this was used to explore the concept of soil fertility and how it influenced decision making

5.Soil fertility

How do you assess what practice is ‘good’?

How do you assess soil fertility?

What indicators are used?

What is good and what is bad for this indicator?

C.3 Farmer indicators per group

Table C.1 Frequency table of the indicators used by trial and non-trial farmers to assess soil health. For each group percentage of total interviews was added because there was a total of 12 trial farmers and 26 non-trial farmers.

Indicator	**Total Frequency**	**Trial farmers Frequency (% total interviews 12)**	**Non trial farmers Frequency (% total interviews 26)**
Yield	24	9 (75%)	15 (58%)
Hard vs soft soil	19	6 (50%)	13 (50%)
Green vs yellow crop	18	4 (33%)	14 (54%)
Soil moisture	16	5 (42%)	11 (42%)
Fast vs slow plant growth	15	6 (50%)	9 (35%)
Soil erosion	15	3 (25%)	12 (46%)
Cob and pod size	14	5 (42%)	9 (35%)
Weed presence	12	1 (8%)	11 (42%)
Crop wilting	10	3 (25%)	7 (27%)
Black vs red soil	9	4 (33%)	5 (19%)
Crop stem strength	8	2 (17%)	6 (23%)
Crop stand	4	0 (0%)	4 (15%)
Germination	3	1 (8%)	2 (8%)
Presence of soil organisms	3	0 (0%)	3 (12%)
Soil texture	3	0 (0%)	3 (12%)
Timing of plant flowering	2	0 (0%)	2 (8%)
Disease presence	2	2 (17%)	0 (0%)

C.4 Total Carbon and Total Nitrogen measurements

*Table C.2 Measured chemical soil health indicators. Values in the same column, depth and location followed by different letters are significations different from each other at α = 5%. SE is standard error. * different letters in the same column, depth and location mean significant difference at α = 10%.*

Site	Depth (cm)		Total Carbon (gkg $^{-1}$)		Total Nitrogen (gkg $^{-1}$)		C/N Ratio		Nitrite & Nitrate (mgkg $^{-1}$)		Ammonium (mgkg $^{-1}$)	
			Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Mwansambo	0-5	CP	14.42a	1.21	0.90a	0.04	15.94a	1.01				
		CAM	14.77a	1.15	0.98ab	0.06	15.07a	0.50				
		CAML	17.73a	1.16	1.19b	0.08	14.98a	0.40				
	5-10	CP	15.82a	1.74	1.03a	0.06	14.98a	0.95	200.69a	30.50	>>	-
		CAM	14.83a	0.88	0.98a	0.05	15.23a	0.51	171.94ab	42.25	>>	-
		CAML	17.62a	1.16	1.11a	0.07	15.91a	0.54	103.33b	34.02	>>	-
Lemu	0-5	CP	9.65a	1.22	0.76a	0.08	12.41a	0.50				
		CAM	11.43a	0.89	0.87a	0.06	13.06a	0.41				
		CAML	12.08a	1.84	0.95a	0.12	12.40a	0.36				
	5-10	CP	10.72a	1.19	0.81a	0.08	13.08a	0.59	62.50a	16.17	75.97a	8.85
		CAM	11.63a	1.00	0.82a	0.06	14.19a	0.70	33.24a	6.80	49.44b	1.62
		CAML	9.67a	1.25	0.74a	0.07	12.94a	0.66	62.22a	16.59	51.67b	2.84
All	0-5	CP	12.03a	0.98	0.83a	0.05	14.18a	0.66				
		CAM	13.10a	0.79	0.92ab	0.04	14.07a	0.38				
		CAML	14.90a	1.21	1.07b	0.08	13.69a	0.38				
All	5-10	CP	13.26a	1.16	0.92a	0.05	14.19a	0.61	131.60a	20.64	-	-
		CAM	13.22a	0.73	0.90a	0.04	14.70a	0.47	104.57a	24.72	-	-
		CAML	13.82a	1.19	0.93a	0.06	14.71a	0.54	82.78a	18.97	-	-
All	0-10	CP	12.65a	0.79	0.87a*	0.04	14.18a	0.45				
		CAM	13.26a	0.55	0.92ab*	0.03	14.37a	0.30				
		CAML	14.61a	0.86	1.01b*	0.05	14.17a	0.33				

C.5 Carbon Concentration 2011 and 2019 comparison

Table C.3 Carbon concentration data for conventional practice (CP) and conservation agriculture (CA) for this study and Cheesman et al. 2016, from the same on-trial farms in Mwansambo and Lemu, Malawi. SED is the standard error of a difference between 2 means (SED) as mentioned in Cheesman et al. 2016

	Depth (cm)	**Management**	**Total Carbon gkg^{-1}**					
			Current study			Cheesman et al. 2016		
			Mean	SED	p-value	Mean	SED	p-value
Mwansambo	0-10	CP	14.9	1.98	0.22	12.55	2.60	0.32
		CA	17.4			15.68		
Lemu	0-10	CP	10	2.14	0.58	11.98	1.30	0.70
		CA	11.2			11.45		

C.6 Infiltration, Bulk Density and Structure

*Table C.4 Measured physical soil health indicators. Values in the same column, depth and location followed by different letters are significantly different from each other at α = 5%. SE is standard error. * different letters in the same column, depth and location mean significant difference at α = 10%.*

Site	**Depth (cm)**		**Infiltration (cms^{-1})**		**Bulk Density (gcm^{-3})**		**Soil Structural Stability Index**	
			Mean	SE	Mean	SE	Mean	SE
Mwansambo	0-5	CP	0.14a	0.01	1.46a	0.03	9.87a	1.31
		CAM	0.14a	0.01	1.44a	0.03	11.59a	1.44
		CAML	0.18a	0.03	1.39a	0.02	12.65a	1.12
	5-10	CP			1.41a	0.03	8.30a	1.21
		CAM			1.45a	0.02	9.76a	1.24
		CAML			1.39a	0.03	10.54a	1.23
Lemu	0-5	CP	0.09a	0.01	1.40a	0.02	7.86a	1.73
		CAM	0.15b	0.02	1.43a	0.02	10.23a	0.85
		CAML	0.15b	0.01	1.40a	0.02	10.95a	1.95
	5-10	CP			1.43a	0.03	9.14a	1.27
		CAM			1.44a	0.02	10.97a	1.45
		CAML			1.50a	0.03	9.44a	1.19
All	0-5	CP	0.11a	0.01	1.42a	0.02	8.87a	1.08
		CAM	0.14b	0.01	1.43a	0.02	10.91a	0.82
		CAML	0.17b	0.02	1.40a	0.01	11.80a	1.10
All	5-10	CP			1.42a	0.02	8.72a	0.85
		CAM			1.44a	0.02	10.37a	0.93
		CAML			1.46a	0.02	9.99a	0.80
All	0-10	CP			1.42a	0.02	8.79a*	0.67
		CAM			1.44a	0.01	10.64ab*	0.61
		CAML			1.43a	0.14	10.90b*	0.69

C.7 Yield

Table C.5 Measured grain yield (kgha^{-1}). Values in the same column, depth and location followed by different letters are significantly different from each other at α = 5%. SE is standard error.

Site	**Treatment**	**Yield (kgha^{-1})**	
		Mean	SE
Mwansambo	CP	3224.50a	191.76
	CAM	5066.87b	196.81
	CAML	5160.27b	304.69
Lemu	CP	2886.03a	140.80
	CAM	3453.80a	240.91
	CAML	2872.30a	180.02

Appendix D: Interview Guide for Chapter 4

Interview themes guide

Interviews took place at a farmer's field and house. If appropriate for explanation and answer it took place while walking through the fields. The interview always started with an introduction, an explanation of what the goal and purpose of the interview was and consent form. Farmers were reminded that they are free to withdraw at any time.

1. Demographics
Family composition
Ages of family members
Education of family members
Household sources of income

2. Farming Activities & Decisions
What are current farming practices on field?
What are the current crops cultivated?
What is the size of land per crop?
Why are these practices preferred?

3.Mapping exercise *(Visual drawing)*
Mapping above practices and crops
What land is rented? Is labour hired?
Why were these practices chosen?

4.Timeline *(Visual drawing)*
Trial farmer
- When started trial?
- Why decided to join trial and how did this process take place?
- Did the trial change their own practices?
- Why did changes in practices occur?
- What were the expectations and were these met?
- How was the reaction to the trial: questions, viewers, 'adopters'?
- Why did they not expand or why did they expand their agricultural practices?

Non-trail farmer
- What changes have occurred in agricultural practices?

When did the change occur?

Why did this change occur?

Why did they not expand or why did they expand their agricultural practices?

CA adoption challenges

What are main challenges for them or others not to adopt CA?

5.Information & knowledge transfer *(Visual drawing)*

From who do they receive information on agricultural practices?

How is this information shared? How frequent?

Creating Influence axis x knowledge axis graph

Ranking of influence and knowledge on agricultural practices

Why is x more influential or knowledge than y?

6.Need & Solutions

What are the main challenges to improving agriculture on their field and in the community?

If the topic of soil fertility already occurred in the above questions this was used to explore the concept of soil fertility and how it influenced decision making

7. Soil fertility

How do you assess what practice is ‘good’?

How do you assess soil fertility?

What indicators are used?

What is good and what is bad for this indicator?

Appendix E: Scoping trip focus group guide

FGDs started with an introduction, an explanation of what the goal and purpose of the discussion was and consent forms. Farmers were reminded that they are free to withdraw at any time.

Trial farmers Ranking FGD

1. Introductions and recalling of what practices are used on trial and own field.
2. Trial experience
    a. Time taken to be comfortable with new practices & process of learning
    b. Understanding of why practices are helpful and what the impact is of the practices.
3. Ranking of 3 practices on the trial *(Visual drawing)*
4. Discuss ranking trials
    a. Why is one practice more successful than the other?
    b. What indicators/observations are used to rank the practices?
    c. How are these indicators/observations used for assessment?
5. How important are these indicators?
    a. Discuss importance

Non-trial farmers ranking FGD

1. Introductions and what practices are used on fields
2. What factors influence decision making on agricultural practices?
3. Ranking the factors. *(Visual drawing)*
4. What observations and information are used to decide on agricultural practices?
5. How are these observations used for assessment (e.g., good or bad)?
6. How do the practices lead to these observations?

Time line FGD (Visual drawing)

Aim: Overtime when did agricultural practice change and why?

’64 independence & ’94 democracy as initial points on the timeline

1. Family/parents/grandparents agricultural practices
    a. Why did this change?
2. Government policies that changed or affected agricultural practices
    a. How did this change agricultural practices?
    b. Why was this changed?
3. When did NGOs or organizations came and influenced agricultural practices?
    a. What practices?

   b. Who promoted them?
   c. When did this happen?
   d. How was is promoted?
   e. Was it adopted?
4. Were there any climatic extremes (floods or droughts)?
   a. What year were these climate events?
   b. How did this change the agricultural practices?
   c. Did anyone give advice or suggestions to change practices?
      i. Who and what?
5. Are there any other events that changed agricultural practices?

Labour calendar (Visual drawing)

During the scoping trip the calendar was drawn once for CA and non CA.

1. When does your agricultural season start?
2. What is the first activity?
   a. How is this activity done?
   b. How long does it take for a specific size of land?
      i. Daily? Or continuous?
   c. How many people are needed for this activity?
   d. Labour hired for this?
3. What is the next activities– repeat until reaching last activity.

Draw calendar and make list of activities

4. Confirm list of activities
5. Make a drawing for each activity
6. What is the first month on the calendar?
7. Put beans on the months according to how labour intensive that month was (total labour)
8. Per month divide the beans over the separate activities
   a. Confirm before moving to next month
   b. Confirm activities for all crops (maize, groundnuts, pigeon pea, cassava, sweet potato)
9. Are there any time conflicts?
   a. What are these conflicts?
   b. How do they prioritize?
   c. How deal with time conflicts?
   d. Is extra labour hired?

Appendix F: Thesis Abstract in Chichewa/ Zotsatira za Kafukufuku mwa Chidule

Kupeza ndinso kupititsa patsogolo njira za ulimi wamakono ndicho chimodzi mwa zinthu zimene zili pa ndondomeko zomwe maiko akukhazikisa pofuna kuthana ndi mavuto a kuonongeka kwa nthaka, kusowa kwa chakudya, komanso kusintha kwa nyengo. Mwa zina, ulimi wa mtayakhasu ndiyo njira imodzi yomwe imalimbikitsidwa ndi cholinga chopitisa patsogolo zokolola ndinso kuchititsa kuti ulimi ukhale opirira kumavuto osiyanasiyana monga kusintha kwa nyengo ndi ena. Ngakhale kuti ulimi wa mtayakhasu waonetsa zotsatira zabwino, makamaka zokhudzana ndi kusamalika kwa nthaka komanso chilengedwe, chidwi cha kafukufuku wambiri yemwe wachitika pa za ulimiwu chagona kwambiri pa zinthu zomwe zingachitise kuti ambiri ayambe kutsatira njira yamalimidweyi.

Kafukufukuyu akuunikira mozama za mmene kamvetsetsedwe ka zinthu kamakhudzira ntchito yopitisa patsogolo ulimi wamakono. Kafukufukuyu wachitidwa m'maboma awiri mu dziko la Malawi. Mabomawa, omwe ndi Balaka ndinso Nkhotakota, ndi ena mwa ma boma omwe bungwe la CIMMYT likugwira ntchito yopititsa patsogolo ulimi wa mtayakhasu kudzera mu minda yachitsanzo. Minda ya chitsanzoyi imagwira ntchito ngati malo amene anthu osiyanasiyana amagawanapo nzeru ndi upangiri wa njira za makono za malimidwe. Chachiwiri, kafukufukuyu akuyang'anaso za mwayi ndinso zotsamwitsa zimene zilipo pa njira zimene zimatsatidwa pofuna kumvesesa maukadaulo osiyanasiyana amene amalumikizana polimbikitsa ulimi wamakono. Izi zatheka pophunzirapo pa za momwe kamvetsetsedwe ka zinthu zinthu kuchokera kwa a katswiri ndinso a dindo komanso anthu ocheza nawo tsikutsiku amagawanirana upangiri wa ulimi wamakono.

Kafukufukuyu wapeza zinthu zingapo zimene zikupereka chithunzithunzi chozama cha ndondomeko zopezera ndinso kupititsira pa tsogolo njira za ulimi wa makono. Izi zili chomwechi kamba ka ndondomeko zomwe zinatsatidwa pochita kafukufukuyu, ndicholinga chofuna kumvetsetsa upangiri wa ulimi wa makono ngati zotsatira za ukadaulo ndinso kamvetsetsedwe ka zinthu mu njira zosiyanasiyana.

Choyamba, kafukufukuyu wapeza kuti pali kusiyana pakati pa ndondomeko zokhazikitsira njira za ulimi wa makono pakati pa mabungwe omwe amakhazikitsa njirazi potsatira luso lopezera njira zothana ndi mavuto a za malimidwe ndinso njira zoyesera mulingo wa kupambana kwa ulimi wamakonowu. Kusiyana kuliponso pakati pa mabungwewa ndi alimi eniyake omwe amapeza njira zonga izi kudzera muzochitika zawo za tsiku ndi tsiku zomwe ndizolumikizana ndi zinthu zochuluka zomwe zimachitika pa minda yawo komanso m'moyo wawo wa tsiku ndi tsiku. Chachiwiri, kafukufuyu wapezaso kuti, pali kusiyana pa ndondomeko zimene alimi eniyakewa amatsata pofuna kupeza kapena kukhazikisa njira za ulimi wa makono zimene angathe kutsatira pa minda yawo. Kusiyanaku kukudza kamba ka zinthu zapaderadera zimene zimasiyanitsa mlimi wina ndi nzake. Izi ndi monga (i) kakhalidwe ka wina ndi nzake ndinso m'mene kamakhudzira kagawanidwe ka upangiri ndi maluso osiyanasiyana, (ii) phindu ndinso zolowa pa ntchito ya ulimi zomwe ndi zosiyana pakati pa mlimi wina ndi nzake, (iii) zinthu zomwe alimi eniyake adakumana nazo m'mbuyo ndinso malingaliro ofuna kutsata njira zokhazo zomwe zili ndikuthekera kopambana kochuluka, (iv) mchitidwe omwe alimi amatsatako zina chabe mwa zinthu zomwe zili pa mndandana wa njira ya ntundu wakutiwakuti ya ulimi wa makono. Chachitatu, kafukufukuyu wakhazikitsa ndondomeko zobweretsera pamodzi ma upangiri osiyanasiyana potengera zotsatira za kuyesa kwa nthaka komanso malingaliro ochokera kwa alimi eniyake. Kugwirizana komanso kusiyana komwe kulipo pa njira ziwirizi kukuthandiza kumvetsetsa mozama za kaganizidwe ka kasamalidwe ka nthaka. Chidwi chomvetsetsa zonse zofunikira pa ntchito yopeza ndi kupititsa patsogolo ulimi wa makono chathandiza kumvetsetsa za mmene okhuzidwa ndi ntchitoyi ndinso ma ubale omwe ali pakati pawo amathandizira kukonza ndikupereka ma uthenga awo okhudzana ndi kupititsa patsogolo ulimi wa makono.

Njira yobweretsa pamodzi ndi kumvetsetsa ma upangiri osiyanasiyana, yathandiza kupereka njira zina zomvetsetsera zovuta zimene zilipo pa ntchito yopititsa patsogolo njira zamakono zamalimidwe, ngakhale kuti pali zina zomwe njirayi siyikadatha kuunikirapo. Mwazina zomwe kafukufukuyu akuunikirapo ndi monga, kupereka mwayi ophunzira kupyolera mu njira zosiyanasiyana, kupereka mpata waukulu othandiza kuti onse ogwira ntchito za ulimi azitha kulumukizana ndi kulankhulana mosavuta pa za upangiri wa malimidwe a makono, ndinso kufunika kounikira ndi kulankhulapo pa mfundo zomwe ndi malingaliro chabe ndinso zina zochitisa kuti ndondomeko zosiyasiyana zikhale zikhale zovuta kukwaniritsa m'madera ena.