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Role of the interaction space in shaping innovation for sustainable agriculture: Empirical insights from African case studies

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A B S T R A C T

The challenges of climate change, food insecurity and land degradation have all led to a push for 'scaling' innovation for sustainable agriculture. For this purpose, international agricultural development projects often use farm trials or farmer field schools as a way for farmers to engage with technically-constructed knowledge and empirical evidence. However, the role of such trials in the socio-political construction of knowledge is often overlooked. This study conceptualises agricultural development interventions as taking place within an *interaction space* between researchers and farmers. Unpacking the processes and dynamics of the interaction space from four case studies across Malawi and mainland Tanzania, we present findings which evaluate: 1) how agricultural innovation takes place in the context of funded agricultural development projects, and 2) how space for technical and social knowledge construction can be opened up or closed down in these contexts.

Results show that farm trials provide a basis for interaction, but that knowledge exchange in these contexts also require knowledge brokers for successful implementation and scaling. Both knowledge brokers, and the trials themselves shape social dynamics, often simultaneously facilitating social learning for some, but contributing to social exclusions for others. A strong connection was identified between the design of the *interaction space* and social dynamics evident within it, indicative of the close interconnection between the processes of socio-political and technical construction of knowledge. Key factors open or close the *interaction space*, such as the continuity of knowledge brokers and the complexity of technologies. Improving the effectiveness of innovation for sustainable agriculture, requires opening up the interaction space to enable more effective and sustained co-creation of technologies, social learning and the collaborative construction of shared knowledge.

1. Introduction

The 'scaling' (e.g., scaling out, scaling up, scaling deep) of technological solutions is central to the objectives of many international agricultural development efforts. The majority of these efforts have been underpinned by a theory of change that assumes the linear transfer and diffusion of effective technologies (Rogers, 2003). Linear models have dominated the global discourse and practice of innovation for sustainable agriculture. The dominant assumption is one whereby knowledge transfers from the 'expert' (often external) to intermediaries (such as extension officers) and finally to, and amongst farmers, through a snowballing effect over space and time. In these linear models, farm trials function as channels for technology transfer through demonstration and persuasion.

The assumptions and approaches underpinning linear technology transfer models have been subject to critical reviews (see Wigboldus

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et al., 2016; Woltering et al., 2019). These highlight the inability of innovation diffusion models used to reflect the complexities and multiple functions of farms, rural livelihood systems and agro-ecosystems (IAASTD, 2009; Pretty and Chambers, 2003), and the failure of technology transfer approaches to transform or improve agricultural production in many parts of Africa. Critiques challenge simplistic assumptions of linear models, demonstrating that the process of scaling is complex and dynamic (Hermans et al., 2020a,b; Leeuwis and Aarts, 2021; Smith et al., 2021; Sumberg, 2017; Wigboldus et al., 2016). Such perspectives contend that technologies are made and re-made across space and time in response to local contexts and through social learning and development (Glover et al., 2019). In this ongoing process of change, farm trials and farmer field schools provide a space where social and technical innovation dynamics interact. As Smith et al. (2021) argue, common reporting still fails to represent these dynamic processes and unintended outcomes. They emphasize the social engagement of farmers with the innovation process, but how both social and technical innovation dynamics play out in this interaction space through top-down and bottom-up processes remain underexplored.

Here we also acknowledge the difference between agricultural innovation types (e.g., innovation for sustainable agricultural) and their respective need for learning processes (incl. extension). Sustainable agriculture, such as climate smart agriculture, are often knowledge intensive (e.g., soft technology), in which case extension is found to play a more significant role in the Global South context (Waddington et al., 2014; Wheeler et al., 2017). In addition, these innovation processes are better supported by diverse sources of engagement and in need of institutional support to sustain long term processes. This underlines the importance of social constructs of knowledge and learning processes, both on the ground and institutional, in the context of sustainable agricultural innovation (e.g., climate smart agriculture).

Alongside a focus on innovation processes in farming systems, critical discussions around the politics of agricultural research for development have exposed some of the knowledge politics that dictate and drive top-down technological development (e.g., Andersson and Sumberg, 2017; Sumberg et al., 2012b; Whitfield, 2015). This literature has critically evaluated the science agendas, institutional norms and assumptions about technology diffusion within a 'green revolution' model of agricultural development. Often in African contexts, agricultural innovation is supported by philanthropic donors from multinational corporations and countries, and have been suggested to sustain an agenda supporting growth and consumption (Brooks, 2015). This business-oriented donor system results in a focus on impact metrics, with high impact targets, and demand for quick results and success stories of 'impact at scale' (Glover et al., 2016; Moseley, 2018; Sumberg et al., 2012a). The critical literature has also questioned how knowledge politics have reinforced a linear technology transfer model and have shaped the modes of engagement and communication (e.g., Leeuwis & Van den Ban, 2004), in particular the role of demonstration plots, farm trials, farmer to farmer extension, use of lead farmers and conventional extension services in providing effective communication for top-down technological development.

To understand the complex systems in which agricultural innovation takes place and specifically explain and analyse agricultural knowledge and information services, different conceptual models have been developed, such as the Agricultural Knowledge and Information System (AKIS) framework and the Agricultural Innovation System (AIS) concept (Klerkx et al., 2012). These models recognise that institutional structures are an important part of agricultural innovation (Spielman et al., 2009) and that social learning takes place within and between these structures (Leeuwis and Van den Ban, 2004). Building on this work, we focus on a specific grounded space in such systems, where social interactions and exchanges of information between different actors and institutions play out in practice, such as in agricultural demonstration sites and farmer field schools, which we collectively label as *interaction spaces*.

We conceive agricultural interventions as socio-political and technical *interactions* through which knowledge is constructed and communicated. We start from the understanding that the spaces in which farmers, extension agents, project implementers, and sometimes even donors interact can offer useful window in to observing the socio-political and technical construction of knowledge, including participation and power dynamics. This work aims to extend the existing literature by evidencing the ways in which this *interaction space* shapes innovation processes in African farming systems. To this end, we draw on the concepts of 'opening up' and 'closing down' in the context of technology and governance processes based on the work by Stirling (2008) and Leach et al. (2010). Both suggest that current exclusive processes of technological change are associated with a closing down of the space for participation and social learning resulting in a 'locking in' to particular pathways of change. In the social appraisal of technology, 'opening up' refers to a pluralistic and conditional approach, with a plural understanding of narratives and framings (Leach et al., 2010; Stirling, 2008). This also concerns the processes of negotiation, with a need to be adaptive, deliberative and reflexive. In the context of externally funded agricultural innovation projects, this negotiation takes place in what we conceptualize as the *interaction space*. Therefore, we conclude by critically discussing the 'opening up' and 'closing down' of this agricultural *interaction space*, to support a better understanding of the interconnection between the socio-political and technical construct of knowledge.

We conceptualize agricultural innovation as a dynamic and multifaceted process, across space and time, in which technology deployment co-exists, and interacts with context-specific socio-political learning. We draw on four case study sites from Malawi (Hermans et al., 2020a,) and Tanzania (Smith et al., 2021), in which donors and researchers have been promoting agricultural technologies and practices with smallholder farmers. Therefore, this paper is a synthesis of case studies to understand where and how socio-technical change is shaped by the relationships between agricultural development interventions, actors, local knowledge exchange and (social) learning processes. Specifically, we examine the social dynamics shaping innovation processes, focusing on the political, technical and social nature of the interaction space. Our study is structured around two research questions.

1. How does innovation of sustainable agriculture take place in the context of funded agricultural development projects?
2. How is space for the technical and social knowledge construction opened up, or closed down, in these contexts?

2. Materials and methods

2.1. Conceptual framing: agricultural innovation networks

We begin with a general concept of the networks and knowledge flows that comprise agricultural innovation (Fig. 1). We highlight how the interface between the *Research & Development (R&D) network* and the *Farm System network* - which we have named the agricultural *interaction space* - plays a critical role in shaping innovation processes (Adolwa et al., 2017; Spielman et al., 2009).

In the *Research & Development network*, the agricultural development agenda is largely donor driven and closely linked to the scientific R&D community, and includes international research institutes such as the Consultative Group on International Agricultural Research (CGIAR), and public and private sector (e.g., agro-dealers, farmer cooperatives, seed companies, contract farming, agribusiness) and agricultural research centre partnerships. Externally conceived agricultural technologies and practices are packaged and disseminated to communities through programmes of intervention, often implemented through multi-stakeholder partnerships involving the R&D community, local, public and private extension services and non-governmental organisations (NGOs).

In the *Farm Systems network,* agricultural innovation takes place

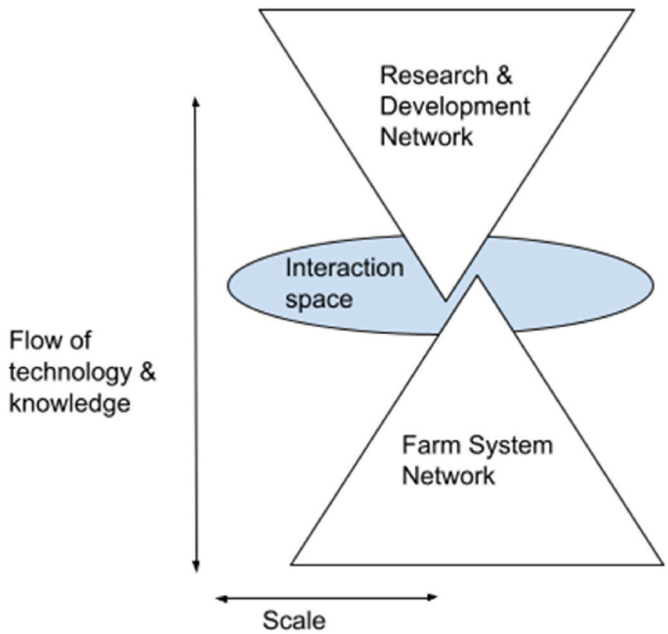

Fig. 1. A schematic representation of the social networks, technology and knowledge flows that comprise agricultural innovation. It indicates that actors from the Research & Development and Farm Systems Networks meet in the interaction space. Through this space the broadly conceived and implemented technologies and knowledges, manifest at a single point in space (e.g., trials) and are shared.

through the sharing, and passing on, of knowledge, which is shaped by the social, cultural and environmental contexts, networks and conditions of a given area (Kothari, 2002). This may reflect the passing on of knowledge gained through field trials and farmer field schools, facilitating the diffusion of innovation. Simple models of innovation diffusion assume that information disperses through communities, eventually reaching indirect recipient farmers (i.e. non-lead farmers) within and beyond the targeted communities. As information is shared, it is modified and adapted to suit the user (Hermans et al., 2020a; Kaluzi et al., 2017; Leeuwis and Van den Ban, 2004). However, flows of knowledge within and across farm systems are typically much less singular and linear. Farmers are active creators, experimenters, users and distributors of knowledge, which include tacit forms (i.e. implicit, intangible knowledge based on experience and practice) and explicit forms (i.e. written, stored knowledge one can reflect on and communicate) (Adolwa et al., 2017; Leeuwis, 2013). This knowledge can be both distinct from that of scientists and extension services (Goulet, 2013) or hybrid through interaction (Hermans et al., 2020a). Learning is informal, conducted between peers (Solano et al., 2003) and through experimentation or knowledge sharing.

Brokerage occurs in the *interaction space.* The *interaction space* is both a physical and social space, influenced by social networks (e.g., *R&D network* and *Farm System network*) which determine the actors (e.g., social interaction) and tools (e.g., trials and farm field schools used as an interaction tool). These spaces are often purposefully created, where agricultural extension officers, or external 'experts' are key knowledge brokers (King et al., 2019; Klerkx et al., 2009). The direct recipient farmers within this *interaction space* are lead farmers, or members of a farmer-field school. Direct recipient farmers receive, interpret and evaluate information about the promoted technologies, adapting them to suit local conditions and knowledge-systems (Glover et al., 2017), and blending local and external knowledge-systems (Munyua and Stilwell, 2013). Such approaches draw on a long history of participation and participatory approaches within agricultural research and development (Chambers, 1994), and represent the performance of a technology, and the interactions between the advocates for the technology and its recipients (Hermans et al., 2020a,). Participatory approaches are not infallible, with shortcomings often attributed to potential domination and vested interests of elite groups, and the marginalisation of others (Cooke and Kothari, 2001).

For innovation and knowledge sharing, relational ties are typically underpinned by trust (Carolan, 2006; Leeuwis and Aarts, 2021), within and across the networks. Trust and distrust are built and both can be a cause and consequence of the interaction space opening up or closing down. For example, distrust may be amplified when prior experiences of 'new' agricultural technologies have been negative or when expectations of an intervention are not met (Frewer, 1999; Ramisch, 2012). It may also support the communication needed to construct the knowledge for more complicated technologies, for which observation alone is insufficient.

In this paper, we aim to evaluate innovation processes within and beyond the *agricultural interaction space,* based on illustrative case studies in Tanzania and Malawi. Understanding innovation processes involves scrutinizing social networks, the relationships between actors (the relational ties) and the processes of knowledge production, sharing and social learning.

2.2. Research approach

To unpack the processes and dynamics of the interaction space we drew together data from two research projects that investigated agricultural innovation across four programmes of Climate Smart Agriculture (CSA) and Conservation Agriculture (CA) intervention. Four case studies from two African countries, Tanzania and Malawi (Fig. 2), were selected for analysis and represent a diversity of actors, interventions and interactions. We provide a short overview of the four case studies below as part of this synthesis study, and more details on the case studies can be found in Hermans et al. (2020a,) for Malawi and Smith et al. (2021) for Tanzania. Ethical consent for this research was granted by the Environment Faculty Research Ethics Committee at the University of Leeds (AREA 17–147 and AREA 18–044) and associated research permissions granted by Lilongwe University of Agriculture and Natural Resources in Malawi and Tanzania Commission for Science and Technology in Tanzania (COSTECH permit numbers: 2019-305-NA-2016-101, 2019-100-NA-2017-46 and 2018-80-NA-2017-340).

The two Tanzania programmes – the European Union's Global Climate Change Alliance (GCCA+) funded 'Integrated Approaches for Climate Change Adaptation in the East Usambara Mountains' (henceforth GCCA-IACCA), and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) implemented Climate-Smart Villages (henceforth CCAFS-CSV) – are located in Muheza (GCCA-IACCA) and Lushoto (CCAFS-CSV) districts in the Usambara Mountains, Tanga Region of north eastern Tanzania (Fig. 2, Table 1).

From 2015 to 2019 the GCCA-IACCA was implemented in eight villages by two Non-Governmental Organisations (ONGAWA and Tanzania Forest Conservation Group) in partnership with Muheza District Council. As part of a suite of activities,[1] the programme promoted CSA techniques and practices through farmer demonstration groups; each comprising 30 farmers, with up to 4 groups per village. Group members volunteered plots of land to serve as demonstration plots, which were collectively managed by group members. During one growing season, the programme trained group members on the practices outlined in Table 1. Community-based trainers were trained, to support wider group learning and post-project continuation of practices.

The CCAFS-CSV programme was implemented in seven villages

[1] Including community-based forestry and alternative income-generating activities (such as beekeeping, butterfly farming, tourism), improved cooking stoves, savings and loans groups, watershed conservation and sanitation projects.

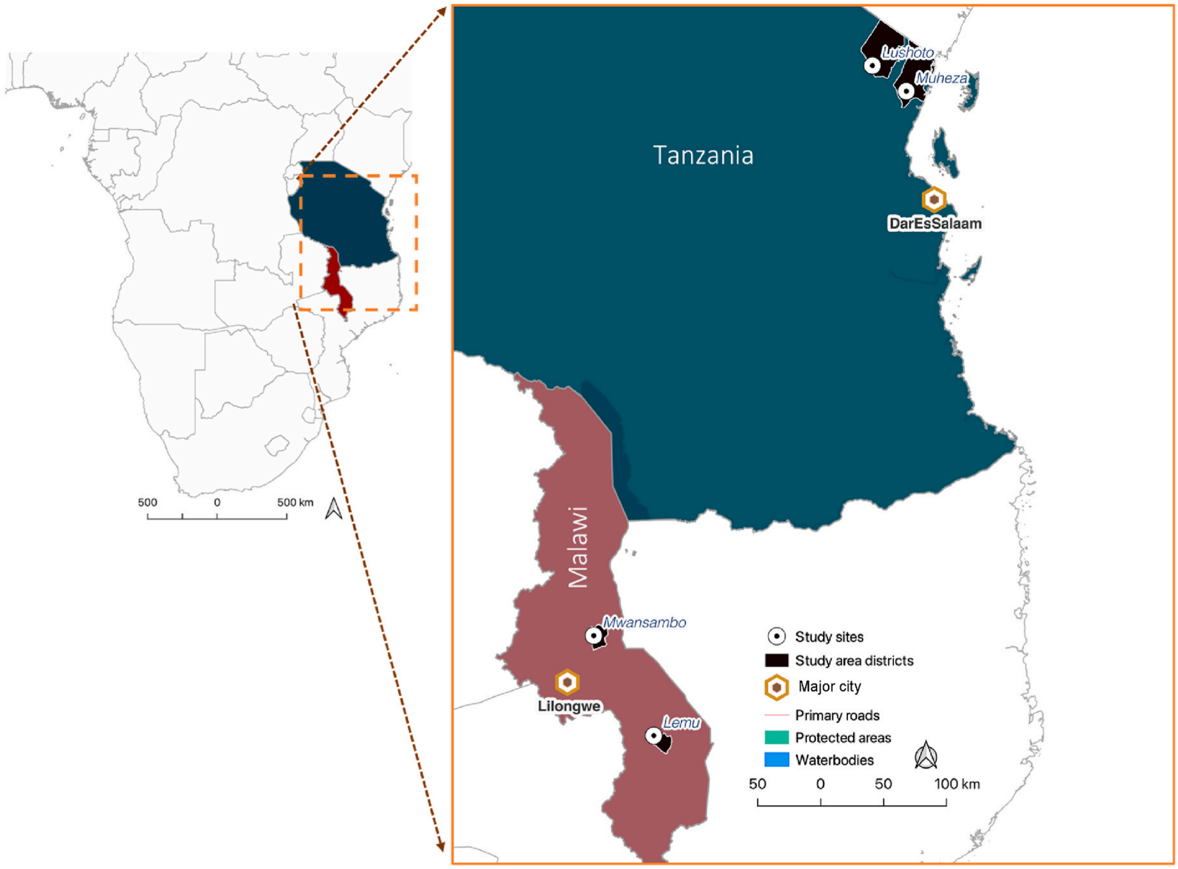

Fig. 2. Case study locations in Malawi and Tanzania.

through a partnership between CGIAR-CCAFS, the Tanzania Agricultural Research Institute (TARI) and Lushoto District Council. The programme started in 2011, and at the time of writing is still currently in operation. In each village, the programme established 20 lead farmers, where each hosted a demonstration plot of CSA activities. Over the course of four years from 2012 to 2016, lead farmers received free inputs (improved seed varieties and fertilisers) and participated in training on a range of activities, outlined in Table 1. Training sessions were also extended to community members, with the lead farmer plots used to demonstrate the technologies promoted.

The two case studies in Malawi focus on farm trials promoting CA by the International Maize and Wheat Improvement Centre (CIMMYT) (Table 1). The first case study is located in Lemu Extension Planning Area (EPA) of Balaka District in southern Malawi, while the second is located in Mwamsambo EPA of Nkhotakota District in central Malawi (Fig. 2). The communities in each area host 6 farm trials led by Machinga Agricultural Development Division (ADD) under the Ministry of Agriculture in Lemu and in Mwamsambo by Total LandCare (TLC), a non-governmental organization that secures funding from various donors to implement development projects in Malawi, Zambia, Tanzania and Mozambique. This is implemented with scientific oversight from CIMMYT. The trials form part of a broader network of 10 communities across different sites in Malawi. Host farmers for the trials (direct recipient farmers) were selected through community meetings with facilitation by extension officers of each organization. Host farmers receive technical support from extension officers, such as in field guidance, research protocols, training and a starter pack with seeds, fertilizer and herbicides. Technology evaluation, including farmers perceptions, are conducted at different stages of the cropping season, with annual review meetings and field days, which are open to other community members to expand knowledge sharing and learning.

The ongoing trials started in 2005 and 2007 in Mwansambo and Lemu respectively supported by various international donors, of which the latest are USAID through its Africa Research in Sustainable Intensification for the Next Generation (Africa RISING) and Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ). They were designed to demonstrate and compare three cropping systems: 1) Conventional ridge and furrow system with maize planted under the Sasakawa[2] system of plant spacing on ridges prepared annually by hand, 2) Conservation agriculture with maize planted with a dibble stick where crop residues are retained on the soil surface on untilled land without ridges, 3) Conservation agriculture (as in system 2), with a maize and legume intercrop, cowpeas in Mwansambo and pigeon peas in Lemu. All trials are rotated annually with groundnuts (*Arachis hypogaea* L.) and pigeon pea alley cropping (also referred to as "doubled-up legume system") (Mwila and Thierfelder, 2021).

2.3. Research methods

Farmer interviews in Tanzania explored periods of learning about the implementation of different agricultural practices in the villages in which the GCCA-IACCA and CCAFS-CSV programmes operated. The interviews comprised a set of open-ended questions and prompts to explore participants' histories of innovation, including their methods of learning and sources of knowledge, their experiences with programme activities and groups, and changes to their farming practices (see Smith et al., 2021 for further details). From July–September 2019, interviews were conducted with 148 smallholder farmers from two GCCA-IACCA

[2] Sasakawa is referred to by farmers as the spacing of 75 × 25cm ridges and planting of one seed per station as introduced by the Sasakawa Global 2000 programme.

Table 1
Interventions, technology and network descriptions per study site.

Case study	Geographic location	Technologies/ practices	Social Networks and interaction space tools
European Union's Global Climate Change Alliance funded 'Integrated Approaches for Climate Change Adaptation in the East Usambara Mountains' (GCCA-IACCA)	Muheza District, Tanzania	Farmer field school with Nursery establishment and techniques for raising tree seedlings[a], Terraces, Contouring, Stabilising plants, Crop rotation and intercropping, Timing of farm activities (e.g., preparing fields ahead) based on climate information, Spacing of seeds, Making and application of compost and manure, Improved seed varieties[b], Homemade organic pesticide, Mulching, Minimum Tillage.	*Research & Development network:* ONGAWA, Muheza District Council, TFCG *Interaction space*: Government extension officers, media, training sessions and farm visits organised by projects. *Farm System network*: neighbours, friends, family, input shops, seed distributors, input shops school.
CGIAR research programme on Climate Change, Agriculture and Food Security - Climate-Smart Villages (CCAFS-CSV)	Lushoto District, Tanzania	Farmer field school with Nursery establishment and techniques for raising tree seedlings[a], Terraces, Contouring, Stabilising plants, Crop rotation and intercropping, Timing of farm activities (e.g., preparing fields ahead) based on climate information, Spacing of seeds, Making and application of compost and manure, Improved seed varieties[b] Homemade organic pesticide, Mulching, Minimum Tillage, Chemical farm inputs.	*Research & Development network:* CGIAR-centers and programmes, TARI, Sokoine University of Agriculture, Tanzania Forest Research Institute (TAFORI), Lushoto District Council *Interaction space*: Government extension officers, government research officer, media, training sessions and farm visits organised by projects. *Farm System network*: neighbours, friends, family, input shops, seed distributors, school
CIMMYT Conservation Agriculture	Mwansambo in Nkhotakota District, Malawi	Trials on *Conservation Agriculture* - Crop rotation and intercropping, Mulching, no-tillage. This also includes new spacing of seeds and improved seed varieties.	*Research & Development network:* CIMMYT, TLC, Local government *Interaction space:* TLC extension officer, Government extension services, farm trials, field and study tours, print media, radio, television & phone *Farm System network:* friends, neighbours, family, traditional authorities
CIMMYT Conservation Agriculture	Lemu in Balaka District, Malawi	Trials on *Conservation Agriculture* - Crop rotation and intercropping, Mulching, Minimum Tillage. This also includes new spacing of seeds and improved seed varieties. 4 Drought Tolerant Maize Varieties (DTV) and 1 non DTV as a control variety were grown both under the ridge and furrow system and Conservation Agriculture	*Research & Development network:* CIMMYT, Local government, *Interaction space*: Government extension officer, field and study tours, print media, radio, television & phone, farm trials, farmer stakeholder panel where government was present. *Farm System network*: family, neighbours, friends, traditional authorities

[a] Spice seedlings (for black pepper, cinnamon and clove) were promoted in the GCCA-IACCA programme and timber trees were promoted in the CCAFS-CSV programme.
[b] The improved seed varieties promoted in the GCCA-IACCA programme included maize, beans and cassava. Improved seed varieties promoted by the CCAFS-CSV programme included maize, beans and potato.

programme villages (75 in total) and two CCAFS-CSV programme villages (73 in total). Respondents were selected by stratified random sampling from the programmes' target populations, stratifying for an equal gender representation. Interviews were conducted and recorded in Kiswahili, and translations subsequently transcribed.

In Malawi, ethnographic approaches involved 38 interviews, 6 focus groups with participatory rural appraisals (e.g., ranking exercises, agricultural practice timelines, field mapping and participatory soil sampling) applied to understand the processes of change in agricultural practices including decision-making, information sources and knowledge development. Participatory rural appraisals were also used as discussion tools during the interviews. Overall, the FGDs provided an overview of priorities and interaction processes, enabling the interviews to go in-depth into these interaction processes. Data were collected in October 2018, and from January–April 2019. Focus group discussions (FGD) were conducted with a trial farmer group (6 farmers who each hosted a CA trial) and groups of non-trial farmers (8–10 farmers), hence a total of approximately 50 farmers. One focus group per community was conducted with trial farmers, and 2 for each community with groups of non-trial farmers. Interviews were conducted with trial farmers and farmers with different social relations to the trials. In these case studies stratified random sampling was used concerning trial involvement and gender. Trial and non-trial farmers were based in the same community implying that non-trial farmers may have passed or observed the trials. However, they have not been involved in the farm-trial set up and did not receive direct instructions from the partners in the Research & Development network.

All interviews were conducted in the local language and recorded. These recordings were translated. The data analysis was based on interview notes and recordings, which were thematically analysed using NVivo and Microsoft Excel. Both deductive analysis, based on the networks and interaction space, and inductive thematic analysis was applied. For the inductive analysis categories were created and combined to form themes, resulting in the themes represented in the results section.

The analysis started from the interaction space framing, as a physical and social space. Actors in the interaction space for each case study were mapped (3.1), followed by evaluating knowledge dynamics among the actors and due to used tools (3.2). Next the influence of the interaction space on innovation for sustainable agriculture decision-making in farm systems (3.3) was explored. This included highlighting main emerging factors and dynamics influencing the opening and closing of the interaction space, namely (Ex)inclusivity (3.4) and the building and eroding of trust (3.5).

3. Results

3.1. Actors in the interaction space

Reviewing the actors and their roles across our case studies, demonstrates that all four programmes of intervention operated through multi-level stakeholder networks, comprised of varied information sources. In GCCA-IACCA programme, interventions were largely funded by the EU and CSA training sessions were co-led by a District Officer, local extension officers and external NGO staff. For the CCAFS-CSV programme, programme activities (e.g., training sessions) were led by a Government Research Officer, in partnership with local extension officers and a plethora of CCAFS staff and affiliated researchers. Whilst there was familiarity amongst farmers with these key individuals, there was often less clarity and differentiation between the interventions and institutional actors they represented, and few farmers were familiar with other project staff:

> *"I learnt from those facilitators, though I have forgotten where they came from, but I remember their leader was [named Government Research Officer]."* (CCAFS-CSV case).

For the CIMMYT CA case studies in Malawi, there has been a history of various institutional actors promoting CA practices including TLC, Concern Worldwide, CIMMYT, and Ministry of Agriculture. Within the current ongoing project, local extension officers were trusted brokers and the main contact points between CIMMYT and lead farmers, who manage the CA trials. Their role was to manage the trials and to share information on results. In Mwansambo in particular, the local TLC extension officer played a crucial role in programme implementation. In interviews with both lead farmers and indirect farmers (i.e. non-trial farmers), the involvement and guidance of this extension officer was reported as a critical convincing factor for farmers to start a farm trial or experiment:

> *"I said yes to this [trial] offer because I knew I would learn a lot from the Total LandCare extension officer"* (CIMMYT case, Mwansambo trial farmer)

> *"I had a lot of trust in [extension officer]'s words despite the bad results in the first season."* (CIMMYT case, Mwansambo trial farmer)

These interactive actors were the main organizers for farmer participation during field days, which were in collaboration with CIMMYT, TLC and local government representatives. The extension officers were therefore the face of the intervention on a daily basis, but the long-standing continuous connection with TLC and local government representatives and CIMMYT created a familiarity for the lead farmers with all institutional actors. Other farmers however were not familiar with the exact names or roles of the institutional actors as these were often collectively referred to as 'externals'.

In each case study, a small collection of key individuals (2–3) played important roles as both knowledge brokers and, when external actors were unknown or new to the area, were important gatekeepers and introducers. These actors were perceived as trustworthy by recipient farmers and were integral to the effective running of programmes and dissemination of information.

In both CIMMYT CA sites and in the CCAFS-CSV site, researchers (including the first and second authors) were an additional common actor. In the Malawian case studies, there were various previous researchers who collaborated with CIMMYT. During individual interviews in the CIMMYT CA site in Lemu, participants raised questions about previous (unrelated to this study) results, signifying that for previous data collections farmers remained unaware of the outputs and that no distinction was made between different research groups and projects. Participants also requested that extension officers shared the results from previous soil samples, however, it transpired that these data were not available, as the extension officer responded that the data had gone 'external'. External here refers to data going outside the local area but without knowledge of where the soil samples are or who has the information. In comparison, research on the CCAFS-CSV site, was coordinated and conducted as part of the wider CCAFS programme, with inbuilt continuous monitoring and evaluation processes for feeding-back results to communities.

3.2. The 'legitimacy' of knowledge sources

Within multilevel stakeholder networks, farmers obtain information from multiple sources, including friends, family, neighbours, village authorities, agro-dealers, extension service providers and radio, and through programme-specific activities such as training sessions, farm demonstration plots and trial sites. This is demonstrated in the GCCA-IACCA case:

> *"I learnt using manure from other colleagues who inspired me very much [...]. We were inspired also by the local leaders who told us that the one who likes to harvest plenty of crops in the farms has to apply manure. During farm demonstration, we were taught how to apply manure and the amount of manure to be applied on every stem." (GCCA-IACCA case).*

Interviews suggested that farmers held some reverence towards certain knowledge sources over others. Knowledge credited to external 'expert' or formal stakeholders, such as extension officers, the radio, and intervention staff and activities, for example, were attributed with higher legitimacy. In contrast, the validity of information obtained from 'local' or informal sources, such as friends and family, was undervalued and disputed, repeatedly described as an opinion as shown in the following responses:

> *"We must be very grateful to that project of farm demonstration, because it has come to clean the darkness before our eyes, [...] after having this education, we got rid of farming through experience and adopted this scientific method of farming." (GCCA-IACCA case).*

> *"I learned for the first time about industrial fertilizers from other farmers here in the village in 2014, but the challenge of learning from other farmers is that everyone tell you different experience and different measurement, unlike learning from experts." (CCAFS-CSV case).*

> *"Information shared from above always has evidence, proof and experience. Neighbours say things in their opinion, not always experience. The lead famer is practicing that thing and talks out of experience but neighbours do not."* (CIMMYT case, Lemu non-trial farmer).

In both the GCCA-IACCA and CCAFS-CVS studies, farmers' perceived confidence in 'scientific' information often corresponded with an interpretation that new technologies or practices were final, and should be implemented exactly as shown on the demonstration plots, or taught during the farm training sessions, without deviation or adaption. Such veneration for the 'scientific' approach meant that some farmers felt discouraged from experimenting with promoted technologies and practices:

> "*No experiment was conducted in the use of improved seeds, as we are advised that experts have already developed them for specific conditions of our farm areas."* (CCAFS-CSV).

The respect (and request) for 'scientific' information to do a 'better' job was also expressed by lead farmers in the CIMMYT CA case study in Mwansambo. In focus group discussions with the trial farmers to reflect on the soil sampling, participants specifically requested data on their trial plots to "*strengthen our knowledge so we can explain it better to other farmers*". In a similar fashion, an interview with a farmer in the GCCA-IACCA site also highlighted the request for education on 'scientific knowledge':

> *"What we need is education, to be more and more informed concerning modern farming methods. For example, in terraces, people cultivate potatoes, sweet potatoes, not Irish potatoes. But the terraces you are talking are the scientific and recommended ones. Even the seeds, once they are planted should be planted scientifically. That is why I tell you we need more and more education. Because we have got manure, what we need is more education."* (GCCA-IACCA case 4)

Unwavering trust in expert information and in scientific approaches led some farmers to internalise blame or place it elsewhere when technologies failed. The GCCA-IACCA programme promoted drought-tolerant bean varieties during an unseasonably wet year. Several respondents held themselves and the weather responsible for the poor outcomes, rather than drawing on the experience of that growing season to evaluate whether or not the variety is appropriate to their context.

3.3. Innovation through and beyond the interaction space

Although 'expert' and 'scientific' knowledge was valued by many participants, farmer-led innovation and social learning played an important role and occurred throughout the farm-system. Almost all farmers, regardless of their involvement with a formal group, learnt some practices and technologies by observing and engaging with neighbours and friends. Likewise, a significant amount of information was inherited and passed down across generations:

> *"Having seen those very colleagues skipping a space from one stem to another, I asked them why they were doing that, and they told me the reason behind. They transparently told me that once you skip a space is when you reap more and more harvests*." (GCCA-IACCA)

> *"My second daughter plants groundnut on flat land and uses mulching. She copied [me] because we farmed together. My other daughter and son plant maize on ridges because they left before I did CA." (CIMMYT case, Mwansambo trial farmer)*

When asked about their parents' influence on current practices, it was commonly shared in the CA study sites that the parents provided the knowledge basis to build on, but that by now parents' influence was limited because it was old information. Following from this, we discussed ways of accessing the 'modern' information, which identified peer learning for seed varieties, plant spacing for different crops or the function of crop residue retention. Elements of the CA package presented on the farm trials were picked up via observation or peer-to-peer learning. One of the farmers in the CA study site in Lemu, who was an active member of a farming group mentioned:

> *"Knowledge is needed because as time is going [the] environment changes and practices as well. These [farmer] groups can know these changes [on practices and the environment]. [Information sharing] has more weight in a club or school[…] Sometimes [the] information [from neighbours] is not true or does not exist. They [neighbours] convince you of something that is wrong, out of jealousy. In a group, they [colleagues] can remind each other of what was shared if someone didn't understand, so checked as group but also shared individually." (CIMMYT case, Lemu non trial farmer)*

The quote indicates a high level of trust in the farmer group as a collective space and preference for mutual support as dynamic social learning with group members, over that of other farm-system actors. Trial farmers noted the importance of farmer groups for enhanced experiential learning and that, for some, groups became their primary information source. Indeed, participants explained how hosting a farm trial on one's farm was considered desirable, given an implied association with extension officers, thus access to their information.

In the CCAFS-CSV case, many participants learnt about improved seed varieties from observing neighbours' successes, thus reinforcing the uptake of technologies promoted by 'experts'. Additional signage on farms, supplied by input shops and the CCAFS-CSV programme, supported observational learning by providing details on seed varieties, and importantly for seed distributors – where to buy them. In contrast, participants in the GCCA-IACCA site described how technologies and practices actively discouraged by 'experts' from the GCCA-IACCA project (specifically the use of chemical inputs), were instead learnt from neighbours, friends and family, challenging the messages from 'experts'. The majority of interview participants in this site acknowledged that the learning gained through farmer groups was of great value, with many participants noting the benefits of a group learning environment.

> *"I feel pleasure for having attended the farm demonstration. Because you cannot do anything alone, but you need a collection of efforts when you join hands with others […], while there, you can ask questions to each other in discussion."*(GCCA-IACCA case).

The farm trials and farmer field schools were popular learning spaces across all study sites, with collaborative, dynamic learning and access to large amounts of knowledge. These spaces supported the creation and building of trust and provided first-hand observation of the benefits of a given practice or technology. Proactive lead farmers often played an extension role, particularly when agricultural extension officers were unavailable. For some respondents, these spaces were empowering, equipping them with knowledge to make evidence-based decisions.

3.4. (Ex)inclusivity in the interaction space

Whereas the group formation in terms of lead farmer clubs or farmer field schools were encouraging and supportive learning environments, they can also be associated with social exclusion. The social dynamics in terms of inclusion or exclusion were often instigated by the existence of clubs creating social boundaries (e.g., lead farmers or farmer demonstration groups) and started with the process of farmer selection. In the GCCA-IACCA programme, a few respondents voiced concerns around selection bias amongst participants. One participant explained how they had dropped out of the sessions, due to apparent nepotism within the groups. We did also gather that sometimes competition among farmers is created as a motivation to catch up with fellow leading farmers.

Interviews in the CIMMYT CA sites showed that indirect farmers perceived lead farmers as receiving support in terms of resources (e.g., fertilizer and herbicides) and knowledge (e.g., extension officer attention). This social observation motivated some indirect farmers to get involved and try new technologies, but others were disappointed by not receiving the same level of support leading to disengagement. Other indirect farmers were hesitant with trying new technologies when not part of a club or without supervision. In particular, the farmers who considered the demonstrated practices as complicated, were demotivated to try the new technology, leading to a self-exclusion from the start. This is reflected in the following quote from a non-trial farmer:

> "*I noticed that he uses manure, planting the groundnut [on the CA flat land] he harvests more because of smaller spacing. But I still use ridges because it is the fast way of farming …. There is a lot happening on this small piece of land, there are maize and groundnut varieties. I also always see him with a tape and I cannot do that.*" (CIMMYT case, Mwansambo non trial farmer).

3.5. Building and eroding trust

The emerging factor determining the effectiveness and role of the interaction space is the building and eroding of trust within the multi-level stakeholder networks. For CA case studies, longevity of engagement has been essential in building trust, with the CIMMYT CA trials having been supported and continuing for over 14 years. Annual site-visits were organised for more senior programme coordinators (actors ordinarily sitting within the R&D network). Over a period of 14 years, successive site visits supported the development of relationships and helped to build rapport between actors in the farm system and the R&D context, to the point where more senior individuals became familiar to lead farmers and were known by name. For indirect farmers, these individuals were described as the '*externals'* who come for reoccurring visits.

Conversely, in some sites, multiple interventions and disjointed co-ordination between them led to mixed or conflicting messaging, resulting in confusion amongst farmers about best practice, and an erosion of trust between interventions, programme implementers and farmer recipients. For example, the GCCA-IACCA programme messaging around organic practices and discouragement of using chemical inputs conflicted with widespread use of chemical inputs in the neighbouring Tea Plantation. In the CIMMYT CA study in Mwansambo, previous promotion of practices of creating new seed and ridge spacing, planting one seed per station instead of three seeds per station and leaving residues in the ridges by the government extension officer conflicted with information given by the Total LandCare officer who discouraged the labour-intensive practice of constructing ridges by hand every year. Likewise, there had been a change in perceived messaging around importing residues for CA, towards only using residues from the field. Previously importing residues from surrounding fields was done by lead farmers to reach the so called *"recommended amount of mulching"* prescribed by researchers during the early years of CA research. Importing residues and other biomass from outside the field in question is now discouraged in the national extension guidelines for CA (National Conservation Agriculture Task Force, 2016) because it is labour intensive and it limits the ability to expand the coverage of CA by leaving other fields devoid of residues. Unfortunately, incorrect technical messages often have deleterious impacts on extension efforts, even after making corrections. In this case, despite this shift, mixed ideas still exist and add to farmer confusion around best-practices.

> "*In the past, I have been told to transport the residues and last week for the first time I heard that crop residues within field should be left.*" (CIMMT case, Mwansambo non trial farmer).

In the CCAFS-CSV case, building on past interventions was a key intervention strategy, as the programme aimed to capitalise on the improved agricultural knowledge and learning gained from past interventions. Again the longevity of an intervention, and in the case of CCAFS-CSV having successive interventions, was considered important in building trust with communities and strengthening the upscaling of promoted practices and technologies. Providing timely agricultural advice and support to farmers, particularly when challenges seem insurmountable, strengthens the trust in key actors and by extension, in an intervention. However, in this same site, challenges with fake 'improved seed varieties' sold by local shops caused widespread loss of trust in improved seeds and local agro dealers. In response to this, the Government Research Officer working on the CCAFS-CSV programme provided support to farmers by providing them with a direct link to improved seed suppliers, circumventing local agro-dealers. Despite a high level of confidence in knowledge brokers throughout the case study sites, trust between recipient farmers and knowledge brokers was fragile, and a single event (e.g., inappropriate advice) could lead to a breakdown in confidence between actors and agricultural technologies.

4. Discussion

4.1. The interaction space

4.1.1. Social networks comprising the interaction space

Based on our case studies we were able to characterise the social networks in agricultural innovation (Section 3.1), which incorporates the actors and relations within and between *the R&D network* and *Farm System network* (Fig. 3*)*. Within the R&D network, we distinguished between the R&D community (composed of actors e.g., CIMMYT, TLC, CGIAR-CCAFS, GCCA-IACCA), who, with support of local government, design and implement agricultural interventions, and programme donors (e.g., IUCN, World Bank, GEF, IFAD, USAID and GIZ), who finance activities and actors as fitting with their agendas. Within the *Farm System network,* we identify two groups of farmers: the direct recipient farmers, and indirect recipient farmers who are expected to 'learn' from the direct recipient farmers according to the linear diffusion innovation models, but are not directly interacting with the intervention. Important to note here is that farmers within these groups still have individual roles, identities and situations that shape their decision-making, and that there is multidirectional peer learning across all farm systems.

Our data highlights how a small number of key individuals play an important role in knowledge sharing and construction within the *interaction space.* These individuals or knowledge brokers are the face of the on-ground intervention in the *Farm System network,* and consist of extension officers, District Officers and NGO staff. In this space the dimension of trust is most dynamic – built and/or eroded over time. The elements within the interaction space (e.g., actors or tools) can also change over time. For example, the local face of the intervention can be consistent, but the intervention and other actors change over time.

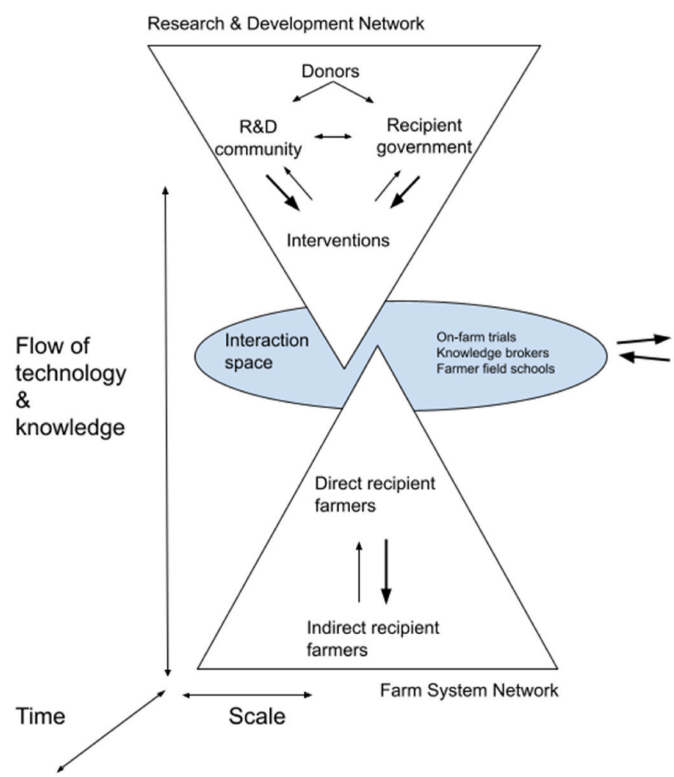

Fig. 3. Conceptualization of the social networks that influence and form the interaction space in agricultural innovation, where the actors of each network and the relations between actors are drawn based on the case studies. The time dimension is added to reflect how these actors and the relations change over time. The arrows reflect the flow of knowledge between the actors. The arrows going in and out of the interaction space reflect the dynamic opening and closing of the interaction space.

Focusing on the agricultural *interaction space* underpins the idea that innovation processes are grounded in the social construction of knowledge – they are not solely a technical process of 'knowledge transfer'. Building on Science and Technology Studies (STS) literature (Crane, 2014; Sismondo, 2010), we observed different interacting forms of knowledge construction in the *interaction space* shaping agricultural innovation: 1) the technical referring to the scientific development of technologies and protocols, 2) the socio-political referring to the knowledge developed through social interactions and relations.

4.1.2. Technical construct of knowledge in the interaction space

Actors within *R&D networks* invest considerable effort in enhancing the technical knowledge base through controlled experimentation and technical measurements of technology performance (Komarek et al., 2021; Mhlanga et al., 2021; Steward et al., 2018; Thierfelder et al., 2016). In the case studies presented here, the technical construction of knowledge takes place through technical evidence building and communication on farm trials. The introduction of agricultural technologies as 'packages' adheres to the technical understanding of innovation. This assumes that agricultural innovation in farm systems evolves through the distribution of set packages, closing down the space for adaptation, experimentation and social learning. However, over time the adaptation of trials based on collective learning or site-specific needs opens the *interaction space*.

Farm trials and field schools provided ways for farmers to engage with the technical construction of knowledge and establish an observable evidence base. Perceived 'expert' scientific knowledge was typically revered among farmers. The legitimacy and trust in this knowledge was high but its technical complexity and protocols also formed a communication barrier. In our case studies, some indirect farmers suggested technologies promoted through farm trials and field schools were too complex and unrealistic due to their perceived lack of access to the resource (e.g., improved seeds, sufficient land and labour) or knowledge support. This shows that farm trials and farmer field schools can become overly complex and challenging to interpret and/or too ambitious, in which case they may be written off by observers as being overly-technical or unrealistic. In these cases the complexity of the technology or trial design and/or the unrealistic scope and/or scale of technologies, can close down the interaction space. Co-creation of practices, training on communication for technical staff, translation to local customs, developing clear coordinated messages, regular evaluations, feedback discussions and monitoring can all provide supporting strategies to overcome these challenges.

4.1.3. Socio-political knowledge construction in the interaction space

Conceptualising farm trials and field schools as *interaction spaces* emphasizes their role as a social space where knowledge is co-constructed and negotiated among actors. In addition to the identified respect for 'scientific' knowledge, there was a high level of trust in the collective learning associated with such spaces. The building of trust through observational verification on trials and demonstrations, and social sharing of knowledge were perceived as useful learning procedures. The farm trials and farmer demonstration groups provide structured and organised interactions and pathways of collective learning and knowledge sharing.

The *interaction space* in these case studies showcase the positive experience of social learning, and the trade-off with affiliated social dynamics that shape the observation and experience of farmers, and the knowledge construction for innovation. Within a social interaction space, direct recipient farmers had a leading role due to their designated role as 'teacher' and their access to knowledge, resources and opportunities. The formation of farmer groups were valuable for collective learning among the involved farmers, which is by no means unique to our case studies (Kilelu et al., 2013). However, for some Malawian indirect recipient farmers the club mentality, and in Tanzania the nepotism of group selection, were perceived as barriers to using and adopting CA and CSA practices. These frictions can be considered as access hierarchies, resulting in exclusion and inclusion dynamics, which is critically discussed as the tyranny of participation by Cooke and Kothari (2001). This type of inclusion and exclusion does not solely result from a singular intervention, but arises from previous experiences with agricultural interventions or the individual attitude of the knowledge brokers (e.g., lead farmers or extension officer) (Hermans et al., 2020a) and social roles (e.g., gender). Some indirect recipient farmers mentioned the trial complexity e.g., *"planting with a marked string looks complicated"*, which resulted in self-exclusion. As a result, interventions may have disempowered indirect farmers, questioning who is responsible for the required conditions for innovation and providing reasons for low rates of use of many technologies.

There was a socio-spatial distinction between farm systems and farm trials, despite being located on farmers' fields. The case studies illustrate that pre-conditions on farm trials were perceived as necessary to replicate the practice on farmers' own fields. Examples of these conditions include applying only no-tillage if there are sufficient residues, the need for hybrid seed varieties, fertilizers, or access to the perceived level of residues. This also highlighted the diversity in implementation, either applying new information sequentially (ladder approach) or as a package (systems approach). Some farmers gained information on 'how' to do practices but expressed uncertainty about the reasoning behind practices (e.g., 'why to do them'). This is important to be able to apply the information as knowledge in other contexts and serves a type of knowledge embedded in capacity building for agricultural development. The knowledge construction for 'why' (e.g., ecological processes) does therefore not directly transfer as evidence for implementation in farm systems. This limitation suggests that the farm trial, as an interaction tool, provides a basis for the *interaction space* but has communication limitations in the opportunity for farmers to engage in useful co-production and negotiation of locally-relevant knowledge.

To address these limitations, the role of knowledge brokers in facilitating learning processes and improving insights for stakeholders into the processes is important. The knowledge brokers in these case studies were identified as the extension officers and local staff, and to a lesser extent the lead farmers. These key individuals across trials and field schools and sites have become gatekeepers of knowledge for innovation for sustainable agriculture and facilitators of multi-stakeholder engagement across the networks within the interaction space (King et al., 2019; Klerkx et al., 2009, 2010). Becoming the 'face' of the innovation requires involvement and presence, building trust between stakeholders over time. This is especially the case when the knowledge broker is connected to promoters and risks being perceived as having personal stakes in the promotion. A good reputation or trust in a knowledge broker can have a positive impact on practice implementation, as demonstrated in the CIMMYT CA study in Mwansambo and CCAFS-CS study in Tanzania where extension officers are specifically allocated to support CA and CSA.

The position of the knowledge broker, through high connectivity or centrality (Janssen et al., 2006), within the farm systems determines the exposure that farmers have to new knowledge and evidence (Arslan et al., 2014; Hermans et al., 2020a,). In addition, the quality of the connections within the social configuration matter. Weak social ties are useful for information acquisition or relatively simple practices (e.g., new seed variety) (Fritsch and Kauffeld-Monz, 2009; Thuo et al., 2014). For more complex knowledge (e.g., CA consisting of various principles), strong ties with trusted bonds are important (Fritsch and Kauffeld-Monz, 2009). To this end, the farm trials or field schools alone will not suffice in construction of knowledge for more complicated agricultural innovations, but the role of trusted individuals and connections becomes crucial.

4.2. The opening up and closing down of the interaction space

Our findings demonstrate that farm trials and field schools provide a space for networks to connect. However, there are limitations in their role as a tool in the interaction space – particularly between innovation networks for farmers and the useful co-production of locally-relevant knowledge for innovation. However, this window can be opened up if there a two-way sustained dynamic learning approach is applied. Focusing on opening up and closing down of the innovation space draws our attention to issues of inclusivity, power asymmetries, trust, and structural barriers to participation.

Within the socio-political construct of knowledge, brokers have a crucial role in opening up this interaction space and insight across the networks. An identified challenge is that 'the transfer of knowledge' through different knowledge brokers, can change the (technical) message. This highlights the critical need for maintaining close links between parties. In addition, the central position, dispositional trust in and affinity with a single knowledge broker can become a limitation (Janssen et al., 2006; Klerkx et al., 2009). For example, in CCAFS-CSV site, there had been continuous involvement of the CCAFS programme trialling and offering training in various seeds, crops and practice, all with the continuity of one key knowledge broker. The trust build-up and effective representation may disappear if the key person is removed. The role of knowledge broker can be taken up by other organisations, but this is challenging in terms of neutrality, funding, overlap in roles and priorities (Klerkx et al., 2009). More knowledge brokers can open up the interaction space, in terms of contact and trust, creating more sustainable interaction for agricultural innovation.

The aim of building evidence and the imperative of achieving impact-at-scale, gives emphasis and legitimacy to metrics of success that are based on numbers of technology adopters (Glover et al., 2019; Hermans et al., 2020a). However, the socio-political complex and dynamic processes in the innovation interaction space, including various knowledges, is not captured in a linear diffusion-based theory of change. An alternative can be a complexity-aware theory of change (Douthwaite and Hoffecker, 2017). This theory acknowledges that technology implementation can be a goal, but also includes the effectiveness of the innovation process, and the capacity building for innovation, and adaptation as important aspects. This translates to the widening of the *interaction space*, with a focus on innovation as a process of socio-political knowledge construction through interaction. At the centre stage of this interaction is the cognitive and communication challenges which currently restrict the legitimacy of alternative knowledges and local experiences framed as being unscientific. To achieve successful scaling of technologies, there is need to engage more with these processes of social learning, instead of solely focusing on the narrow technical construction of knowledge.

The role of the farm trials as a tool in scaling is place-based but orchestrated by the R&D network. Some of the case studies presented were unique in their ability to run long-term (>10 years). There was a variety of interventions: in CIMMYT CA case studies there was a focus on long-term evidence building for a particular package of practices, whereas in CCAFS-CSV the R&D agenda was focused on demonstrating a range of technologies (basket of options). Finding long-term donor funding for farm trials puts pressure on R&D organisations and local government to build evidence and 'success' stories to make a case for future funding applications (Sumberg, 2017). This pressure influences the interaction space, in terms of what agendas and agricultural innovations are implemented and can narrow the interaction spaces through focus given to implementation of strictly defined technologies, with little room for experimentation, or limited and short-term interaction. However, short-term projects are equally pressured by a lack of time to experiment and adapt. For example, within the GCCA-IACCA programme with short project duration, as required by the donor, there was anomalously high rainfall during the key implementation period. In the context of greater climate variability, longer running programmes allow for more trust-building and learning under varying environmental conditions. The ability to show a range of technologies over a long period of time can open up this interaction space and provides a platform for deeper learning and knowledge transfer.

By emphasizing the socio-political dimension of agricultural interventions, this evidence also underlines the importance of institutional structures, including policies. Important elements here are fostering local contextualisation of interventions with multiple knowledge brokers, long-term support for capacity building and programs, and implementation of the above elements which can open up an interaction space. These include moving away from technology transfer and adoption metrics for success, and towards an emphasis on opening up space for social learning and the collective innovation process (e.g., focus on spaces being inclusive, long term and interactive).

Participatory and more broadly framed innovation processes can open up the interaction space, leading to space for both technical and socio-political knowledge construction with an emphasis on transparency and trust building. Just suggesting participation is, however, insufficient as it still can create epistemic injustice (e.g., dominance of technical knowledge) or social ranking. In the process of innovation in the *interaction space*, there is a politics behind the privileging of certain knowledges and knowledge processes over others, which is only sparsely reflected on as it concerns both the role of farmers and scientists (e.g., Boogaard, 2021). The level of participation during evaluations, field days, farmer field schools or farm trials, depends on facilitation and follow-up or long term interaction (Ramisch, 2012). This provides a challenge for an agricultural innovation network dependent on donor-driven R&D, since long term programmes are costly. It requires a shift in funding practices that focus on long term impact and improving implementation through social collaborative learning. In addition, shifting from donor-funded projects to governmentally-led interventions could overcome this hurdle.

5. Conclusion

In this study, we use the concept of the *interaction space* as a means to explore the social dynamics and knowledge dimensions of innovation for sustainable agriculture. Focusing on the *interaction space* underpins the idea that innovation processes build on social constructivism and are not solely a technical process of 'knowledge transfer'. Based on four case studies across Malawi and Tanzania, in which externally funded interventions have been promoting agricultural technologies and practices to smallholder farmers, we used the concept of '*interaction space'* to understand how agricultural innovation is shaped in farm systems.

Farm trials provide a tool for the *interaction space* but have limitations in the opportunity for farmers to engage in useful co-production of locally-relevant knowledge. In overcoming these limitations, the role of knowledge brokers, as the face of the innovation, in facilitating learning across social contexts is important. There is limited insight for farmers in the wider innovation networks, relying heavily on the knowledge broker role, and shaping social dynamics within the socio-political construct of knowledge. Importantly, there is a strong connection between the *interaction space* design and the connected social dynamics (e.g., inclusion, exclusion) and social learning. This highlights the close interconnection between the socio-political and technical construct of knowledge.

The process of knowledge construction for agriculture is dynamic, changing over time (e.g., trust relations, collaborative working) and subject to a diversity of interventions with different purposes (e.g., long term promotion of one technology package or demonstrating a multitude of options). Factors such as a central point of one trusted knowledge broker who is removed can be unsustainable and close the interaction. Systematic opening of the interaction space, with transparency and trust building, requires acknowledging the integration of the socio-political and technical knowledge construction. This would be prioritising the process of social learning over a focus on technical knowledge, considering the running time of interventions, diversification of knowledge brokers, methods of communication, and type of practices promoted.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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