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ICTs, smallholder agriculture and farmers' livelihood improvement in developing countries: Evidence from Tanzania

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Abstract

Information and Communication Technologies (ICTs) are among the profound tools to help the poor and marginalized rural smallholder farmers make a difference in their lives. This paper seeks to understand how the recent development of ICTs helps increase agricultural productivity and improve smallholder farmers' livelihoods in Tanzania. We employed a fuzzy sets Qualitative Comparative Analysis (fsQCA) technique to select the most relevant 24 literature from 2163 literature and analyze the drivers (*conditions*) that influence ICT use among the smallholder farmers, which in turn leads to increased agricultural productivity and improved farmers' livelihoods (*outcomes*). In addition, the authors conducted in-depth interviews with some local smallholder farmers in Tanzania's same regions, as shown in the reviewed literature, to understand how ICTs worked in the field. Findings revealed that ICTs had been increasingly used for and directly linked with agricultural transformation, increased agricultural productivity and improved rural livelihoods in Tanzania in the past two decades. Smallholder farmers rely on ICT tools, particularly mobile phones and radios, to access agricultural-related information, which helps them increase agricultural productivity. The limited number of public extension service agents forces most smallholder farmers to opt for ICTs as an alternative source of agricultural information. In this case, the agricultural extension department from the ministry of agriculture should work closely with telecom, broadcasting companies and other stakeholders to strengthen and initiate more appropriate ICT infrastructure and services targeting the smallholder farmers.

Keywords

ICTs, smallholder agriculture, livelihood improvement, developing countries, Tanzania

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Introduction

ICTs—both modern and traditional—are considered to be among the profound tools that can help poor and marginalized rural smallholder farmers make a difference in their lives (World Bank, 2017). This paper seeks to understand how the recent development of ICTs can help smallholder farmers to transform agriculture, reduce poverty and improve farmers' livelihoods in Tanzania. This is because agriculture is still the mainstay of the country's economy and employs almost two-thirds of the entire population (Epaphra and Mwakalasya, 2017; FAO, 2014; World Bank, 2019). Besides that, the sector is still dominated by

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small-scale subsistence farms despite the slight growth of medium-scale farms, which are more commercialized, mechanized, and specialized (Krone et al., 2016; Wineman et al., 2020). As it is in many other developing nations, particularly in sub-Saharan Africa (hereafter SSA) (FAO, 2018; Mapiye et al., 2021; Minot and Sawyer, 2016), smallholder farmers in Tanzania face different challenges, including the lack of sufficient information on methods of production and market opportunities, especially for novel crops and varieties. They also lack the necessary financial reserves to invest in new crops, which can be linked to the collateral shortage, which limits their access to credit mainly from formal financial institutions.

Furthermore, smallholder farmers living on or near subsistence are risk-averse because they produce first to ensure a minimum food supply before producing cash crops for the market (Minot and Sawyer, 2016). They also face climate-related problems where they are mainly less informed about this particular problem (Barakabitze et al., 2017; Ndimbo et al., 2021; Tumbo et al., 2018). These challenges make smallholder farmers vulnerable to poverty, hunger, and malnutrition. Nevertheless, rural livelihood transformation and poverty reduction can easily be achieved through transforming smallholder agriculture. Understanding how different sub-sectors like ICT promote agricultural growth is vital for academics, researchers, policymakers, and development practitioners. ICTs can be a panacea to some agricultural challenges due to their ability to offer timely and cost-effective services to farmers (Aker et al., 2016; World Bank, 2017). These technologies have been surging in the twenty-first century. They are now widely used to transform developing countries' agriculture by facilitating access to agricultural information, knowledge, and technologies (Folitse et al., 2019; Khan et al., 2020; Mapiye et al., 2021). ICTs are essential tools to empower people (Subejo et al., 2019). Access to and use of information has been a prerequisite for developing and growing agriculture and other economic sectors.

In Tanzania, as in many other countries, ICTs are widely recognized for supplementing the traditional extension service system, which requires direct contact between extension workers and farmers (Sanga et al., 2014). Different ICT tools, ranging from traditional (e.g., print media, magazines, newspapers) and the more modern ICT tools (e.g., mobile phones, radios, televisions, websites, and social media), have been employed by the private and public extensions service agents to reach the majority of smallholder farmers across the country. As previously stated, smallholder farmers face challenges in accessing agricultural information, including information related to agricultural extension and market, due to a limited number of public extension service workers who should visit farmers in their fields and provide agricultural advisory services (Karanja et al., 2020; Tumbo et al., 2018). While the World Bank recommends 1:200–500 as a sufficient ratio between agricultural extension officers and farmers, the situation is different in Tanzania, where the ratio between extension service officers and farmers is 1:1172 for crops and 1:500 for livestock farmers. Interestingly, this ratio is also lower than the standards set by the ministry of agriculture of Tanzania of having at least two extension officers in each village across the country (Busungu et al., 2019). Besides, the available public extension service officers can serve only 10% of the country's farming households (Hella, 2013). The emergence and rapid surge of ICTs are considered a panacea to some ongoing agricultural-related problems in Tanzania and many other developing countries.

Therefore, smallholders' access to agro-based information is hampered by Tanzania's small number of extension workers (Karanja et al., 2020; Tumbo et al., 2018). ICTs, mainly radios and mobile phones, continue to be the best alternative tools for smallholder farmers to access agricultural information, mainly information related to the selection of seed varieties like drought-resistant seeds, how to plant, how to use fertilizers and managing fertility of the soil, diseases and pests' control, weeding, harvesting and avoid post-harvest loss (FAO, 2018; Kiberiti et al., 2016; Silvestri et al., 2021). Radios and cell phones also make it easier for smallholder farmers to access market, technical, and weather information (Kiberiti et al., 2016; Krone et al., 2016; Mwalukasa, 2013; Okello et al., 2020; Sife et al., 2010). ICTs primarily use the Swahili language to disseminate agricultural information because Kiswahili is Tanzania's most widely spoken and official national language (Silvestri et al., 2021). Some local and community radio stations broadcast in vernacular languages, facilitating the use of agricultural information by farmers of all educational levels (Okello et al., 2020).

Research question

Building on secondary data sources and in-depth interviews, this paper intends to answer one fundamental research question:

- How and in what ways do ICTs help smallholder farmers to increase agricultural productivity and improve farmers' livelihoods in Tanzania?

The paper is limited to two main ICT tools (radios and mobile phones) since they widely communicate agricultural information in Tanzania as most smallholders have access to or ownership of radios and mobile phones compared to the others (Quandt et al., 2020). Based on the information from Tanzania Communication Regulatory Authority (TCRA), the number of people using mobile phones and internet services has increased in the past ten years. In 2012, mobile phone subscribers surged to around 27 million. The number of subscribers surged to around 39 million in 2015 and 40 million in 2016. From 2018 to 2021, mobile service subscribers increased rapidly to around 54 million subscriptions (TCRA, 2022).

Furthermore, the number of internet users has rapidly increased in Tanzania following the increased use of smartphones in rural and urban settings. As of March 2022, TCRA estimated that almost 50% of Tanzanians use internet services (TCRA, 2022). Although TCRA does not give specific details on the number of rural and urban subscribers, it is possibly true that the number of urban mobile phone subscribers outpasses that of the rural counterparts. Besides, radio stations have increased rapidly from a single radio station during the early years of independence to 193 radio stations in 2022. Some have national coverage, while others have regional, district, and community coverage (TCRA, 2022). Trade liberalization of the 1980s is cited as the leading cause of the increased number of radio stations and telephone users in Tanzania (Sife et al., 2010). As a result, ICT-based programs can more easily reach the vast majority of smallholder farmers who previously could not access agricultural information due to the limited number of government extension service personnel.

Critical issues on ICT in agriculture

The rapid growth in ICT innovation and application in different sectors has been surging since the 1980s, particularly in the Global North. Since the beginning of the twenty-first century, ICTs have been increasingly integrated into different developmental sectors in the Global South and SSA in particular. The agricultural sector is not exceptional in these global technological changes and innovations (Deichmann et al., 2016) since new technologies have penetrated the countryside and shaped agriculture from the production step to the consumers' table. Through the development of ICTs, different social actors in the agriculture value chain can easily interact and communicate information related to agriculture such as information on agricultural knowledge and technologies, financial services, weather and climate change-related information as well as market information. ICTs also play a great role in improving farmers' management and decision-making abilities (Panganiban, 2019).

Do ICTs really improve the situation of the poor? This is one of the critical questions central to ICT research and practice. Some recent critical publications on the nexus between ICTs and development (see for example Harris, 2016; Schelenz and Pawelec, 2022) shade the light on the critique of some of the so-called information and communication technology for/and development (ICT4D/ICTD). Schelenz and Pawelec (2022) put forward several criticisms that are essential to the students, researchers and practitioners, particularly those who are new to the field of ICT. Some critical issues on the practice of ICTs presented in their article include the problem of Eurocentrism, modernity bias and high techno-optimism in ICT4D where modernization and Eurocentrism have dominated the field. Regarding excessive techno-optimism, Schelenz and Pawelec (2022) point out that "Many scholars fear that technology designers, funding bodies and companies are overly optimistic about the impact of ICT on socio-economic development". Nevertheless, the reality on the ground might be different from the initial expectations and instead of accelerating socio-economic change, ICTs may worsen it by promoting power inequalities. Besides, pervasive problems of the 'digital divide', that is, lack of physical access and inability to use ICT innovations are still apparent, particularly in poor rural areas in the Global South (Panganiban, 2019). The digital divide makes the excessive techno-optimism unrealistic in some local contexts especially in developing countries.

Harris (2016) points out another critical issue stating that in most cases, the practice of ICT 'fails the poor' by showing that "while ICT4D researchers are interested in influencing both practice and policy, they are less inclined toward the activities that would make this happen, especially engaging with users of their research and communicating their findings to a wider audience". This implies that ICT research and practice in different sectors such as

agriculture neglect the important role of communicating findings to the public that could help to transform the livelihoods of marginalized people, particularly poor farmers. Besides, even when findings are disseminated to the users, the critical question is concerning how those findings are disseminated, by who and through which channels. Some research reports that most ICT initiatives that aim to transform agriculture in many developing countries fail to achieve the intended results due to "tight funding, lack of physical infrastructure, deficiencies in human resources and incompatibility of programmes to realities on the ground" (Panganiban, 2019). However, this failure does not imply that ICTs contribute nothing to the development of the agriculture sector in these countries since ICTs have been reported to contribute positively to the agricultural transformation in the Global South particularly in the past two decades (Asenso-Okyere and Mekonnen, 2012; Deichmann et al., 2016; Min et al., 2020).

Some critical research such as Krone et al. (2016) points out that despite the positive potentials and achievements that ICTs have brought to the agriculture sector, "there are also more critical notions on ICT for farming in developing countries which indicate that ICT might be overestimated and/or lead to negative developments". Overestimation of the positive outcomes of ICTs is highly associated with what Schelenz and Pawelec (2022) term as excessive techno-optimism that results in the so-called 'technotopia'. Besides, the promising positive outcomes of ICTs do not mean that ICTs can address all challenges faced by farmers. The truth is that "technology can always only address some, but not all of the barriers faced by farmers in poorer countries" (Deichmann et al., 2016). Krone et al. (2016) suggest that the influence of ICTs in agriculture is dependent on the different farmers' capabilities such as education and financial capability. Differences in farmers' capabilities are the reasons why some farmers are more successful in integrating ICTs into agricultural development. Other important factors that could make ICTs more useful include user-centrism, paying attention to local conditions, and sustainability issues (Schelenz and Pawelec, 2022).

Our study pays attention to the critical issues raised in the literature and that is the reason why we use two approaches to address the research question. First, we survey the scholarly literature to explore what has been written concerning the nexus between ICTs, agricultural productivity and farmers' livelihood improvement. Secondly, we use in-depth interviews to justify the information obtained through secondary data sources. A detailed description of the two approaches is presented in the following part. Besides, the conclusion of the study remains user-centric, that is, it mainly presents issues that could help to appropriately solve the farmers' problems and improve their situation.

Methods and materials

Methods

This study draws on the scholarly literature to describe how ICTs enhance agricultural productivity and improve smallholder farmers' livelihood in Tanzania. After identifying the critical question of this study, the authors identified the important keywords that helped get the relevant articles. The keywords identified include "information and communication technologies (ICTs)", "ICT4D", "new technologies", "radio", "mobile phones", "SMS-based agro advisory", "smallholder farmers", "agriculture extension", "agriculture information", "agriculture development", "agricultural productivity", "rural development", "poverty reduction", "livelihood improvement" and "Tanzania". These keywords were used to develop search strings based on the search engines. Afterwards, relevant articles were obtained through different search engines, including Web of Science, ScienceDirect, and Google Scholar. Articles were first selected based on relevance by considering the titles, abstracts, and full papers. Besides that, a snowball search strategy was also employed, whereby snowballing the reference list in reviewed articles added more studies to the review. We obtained 2530 results in our initial search, which included all documents related to ICTs. After screening based on articles, we then obtained 2163 results. After that, we screened the results based on the year of publication (2010–2022), where we obtained 1521 results. The next step was to select those covering information on the Tanzania case, where we obtained 111 results. After reading titles and abstracts, we came up with 43 research articles. The final step was reading the full articles to obtain articles relevant to our research question. We finally remained with 24 articles that met the review criteria. The overall process of the literature search is shown in Figure 1 below.

In addition to the secondary data sources, the authors conducted in-depth interviews with some smallholder farmers in the same regions of Tanzania, as shown in the reviewed literature (Table 1). A total of 26 in-depth interviews were carried out with smallholder

farmers between May to August 2022. The main criteria used to select the respondents was the engagement in any agro-related activities such as crop farming, animal keeping, beekeeping, fish farming and agro-forestry. Another minor criterion included age where adult respondents, aged 18 years and above were recruited for the study. In-depth interviews were useful in gathering respondents' experiences, expectations, and thoughts on using ICTs to access agricultural information, improve agricultural productivity, and enhance livelihoods (Boyce and Neale, 2006; Deterding and Waters, 2021; Eppich et al., 2019). Combining literature review and in-depth interviews was crucial in this study since interviews helped to supplement and strengthen findings obtained through a scholarly literature search. The researchers intended not to show the superiority of one approach over another; instead, they intended to use the strengths of both approaches and draw out the nuances in a way that neither of the approaches can do on its own. The in-depth interview guide used in this study is attached in Appendix A.

Inclusion and exclusion criteria

Our review process was guided by eight inclusion and exclusion criteria (Table 2): firstly, publication language, where only articles published using English were included. Secondly, publication date whereby only articles published between 2010 to 2022 were included in this review. This is simply because, in many developing countries, including Tanzania, the use of modern technologies has increased since the late 2000s. Thirdly, the ICT tool was emphasized on mobile phones and radios since many rural dwellers can access and use these ICT technologies in their daily lives. Fourth, our study is limited to research articles on ICT narrating the integration and use of ICTs in the agricultural sector. Fifth, the geographical location of this study was limited to a single country, Tanzania. Sixth is relevance to the study question. The articles included only describe the role of ICTs in the agriculture sector. Seventh is the type of publication where only peer-reviewed articles were included. Lastly is the type of research method whereby the study used qualitative and quantitative studies were included, given the nature of the analysis approach technique adopted in this study (fsQCA). After carefully following the inclusion and exclusion criteria, the final decision was to choose 24 articles for review. The researchers, therefore, did not review articles beyond the set criteria.

Data analysis

We use a fsQCA to analyze the relationship between using ICTs and improved agricultural productivity, leading to improved farmers' livelihoods. Social scientist Charles C. Ragin initially developed this approach in the 1980s (Marx et al., 2014) to take advantage of "both qualitative (case-oriented) and quantitative (variable-oriented) techniques" (Rihoux and Ragin, 2009). QCA was initially used in the field of comparative politics and historical sociology. However, it is now used in many other fields, including information studies (Fernández-Esquinas et al., 2021; Mendel and Korjani, 2012), business (Coduras et al., 2016; Valaei et al., 2017), education (Choi and Lee, 2015; Van Mieghem et al., 2020) and many other fields. The method allows researchers to generate linguistic summaries from case-related data. Different from quantitative methods, which "are based on correlation, fsQCA seeks to establish logical connections between combinations of causal conditions and an outcome, the result being ruled that summarizes the sufficiency between subsets of all of the possible combinations of the causal conditions (or their complements) and the outcome" (Mendel and Korjani, 2012).

While the original QCA—crisp-set QCA—only indicated the presence or absence of conditions that resulted in an outcome (Rihoux and Ragin, 2009), fuzzy sets are more appropriate because they allow the "calibration of partial membership in sets using values ranging from 0.0 (non-membership) to 1.0 (full membership)" without ignoring underlying set-theoretic operations and principles (Ragin, 2008). In contrast to conventional Boolean or crisp set QCA, which analyzes data as either entirely in (1) or fully out (0), fuzzy sets analyze data based on a three-value set, a four-value set, a six-value set, and a continuous fuzzy set (Rihoux and Ragin, 2009) to indicate the extent to which values are either entirely in, fully out, or neither fully in nor out. The distinctive strength of QCA falls on its ability to conduct case-oriented, inductive research. However, as compared to csQCA, fsQCA falls short in supporting contradictory conditions. This inability to support contradictions remains one of the significant limitations of fsQCA (Rubinson, 2013).

The fundamental premise is that agriculture, which serves as the foundation of the rural economy in SSA and Tanzania, is partial to improving smallholder farmers' livelihoods. However, transforming this

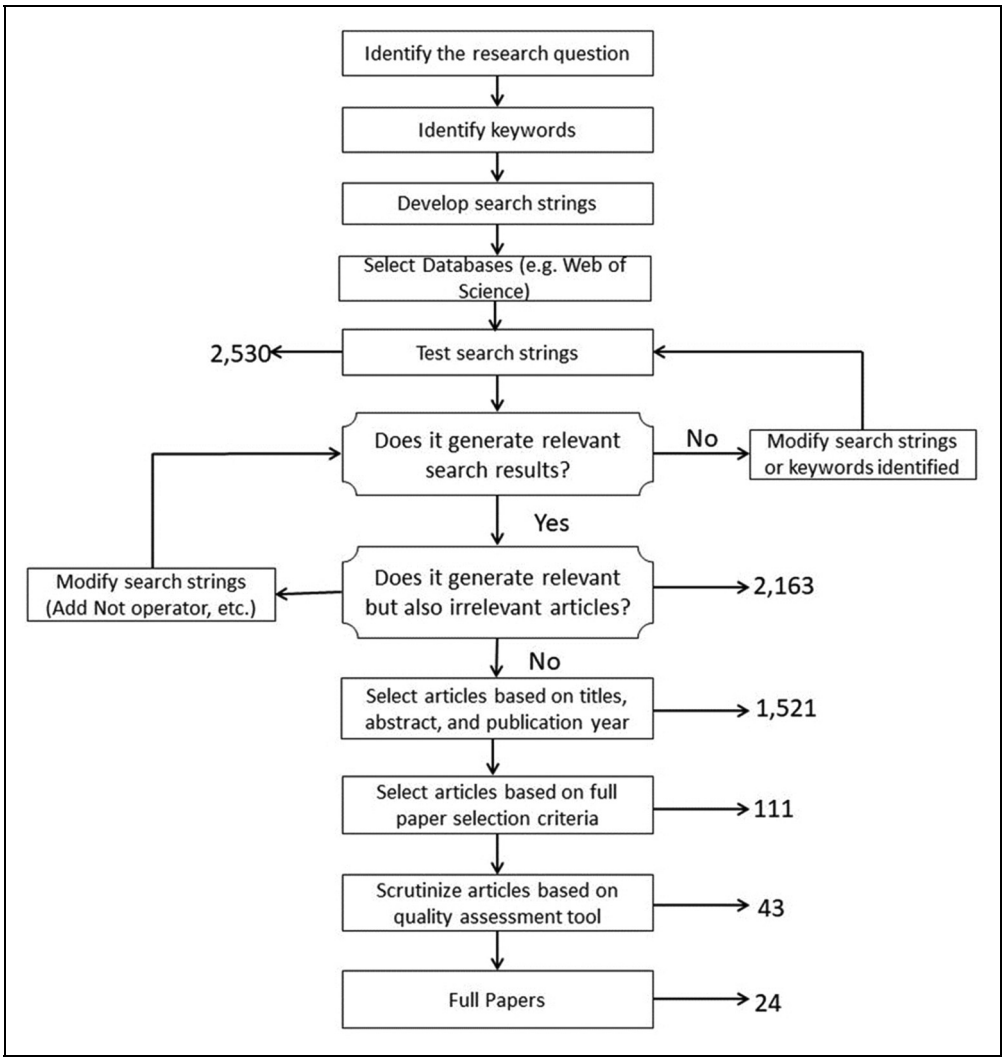

Figure 1. The process of literature search.

sector needs an active role played by ICTs, particularly mobile phones and radios since the conventional extension system could not reach the majority of the smallholder farmers due to the limited number of public extension service workers (Karanja et al., 2020; Tumbo et al., 2018). To obtain the intended results, we developed four (4) ways (*conditions*) in which ICTs help smallholder farmers to increase agricultural productivity (Pro), improve their livelihoods and promote rural development (*outcome*). These conditions include knowledge (Know), market (Mark), finance (Fin), and weather (Weat), as described in Table 3.

As indicated earlier, our literature review is limited to 24 studies (cases) that, in one way or another, report the nexus between ICTs' use with farm productivity among smallholder farmers, which leads to improvement in livelihoods. In order to obtain the intended results and ease the analysis, we used codes [1] and [0] to indicate the presence or absence of a condition or an outcome in a selected literature/case, respectively. According to Ragin (1987), coding the selected variables is a preliminary step in QCA. This coding resulted in a data matrix that contains 1 s and 0 s for each of the 24 reviewed articles. The last column of Table 2 above shows the number of cases corresponding to the conditions.

As in other methods, our analysis starts with showing the analysis of the variables' descriptive statistics. Hereafter, the raw values of every variable were standardized to tackle the problems of standard deviation and mean. In this step, the fuzzy-sets membership score for each variable was generated using the fsQCA calibrate function. Since the calibrate

function requires the reference points of three values, we adopted 0.95, 0.05 and 0.5 to indicate whether or not sets are full membership, full non-membership and neither in nor out of the set, respectively. After this step, we constructed a truth table before analyzing the necessary conditions. Besides, qualitative content analysis was used to analyze information obtained through in-depth interviews (Lindgren et al., 2020).

Analysis and results

Descriptive statistics

Table 4 below shows descriptive statistics for the variables (conditions) investigated in this study. These values comprise the mean, standard deviations, the minimum and maximum values of the variables, the number of cases and missing cases. The analysis

Table 1. A summary of the regions based on the reviewed literature and interviews conducted.

SN	Region Name	No. of literature reviewed per region (out of 24)	No. of interviews
1	Arusha	4	3
2	Dar es Salaam	3	1
3	Dodoma	3	1
4	Iringa	4	2
5	Kagera	1	0
6	Kigoma	1	0
7	Kilimanjaro	7	3
8	Lindi	3	1
9	Mbeya	5	2
10	Morogoro	16	5
11	Mtwara	5	2
12	Mwanza	2	1
13	Ruvuma	2	3
14	Songwe	1	1
15	Tanga	3	1
16	Northern and Southern Highlands of Tanzania	1	-
Total			26

Note: The total number of literature reviewed from each region differs from the total number of literature reviewed in this study since some studies cut across several regions.

Table 2. Procedures for inclusion and exclusion criteria and rationales.

Criteria	Decision	Rationale
Language	English	Authors are fluent in this language
Date of publication	2010–2022	The use of modern technologies in Tanzania and many developing countries has increased since the late 2000s
Type of ICT tool	Mobile phones and radios	These are the primary ICT tools used by the rural smallholder farmers in Tanzania
Industry	ICT and agriculture	Agriculture is a mainstay of more than two-thirds of the population. Linking it with the ICT sector could help to bring significant changes
Geographical location	Tanzania	The study focuses on Tanzania, though insights from studies carried out in other countries are also welcomed
Relevance to the review question	Should be relevant	Addresses a review question
Types of publications	Journal articles	Peer-reviewed articles are mainly used since they provide more empirical evidence.
Research methods	Both qualitative and quantitative studies	The analytical approach (fsQCA) adopted in this study allows for the combination of both case-based and variable-oriented techniques

Source: Authors' formulation

Table 3. Hypothetical conditions and outcomes on ICTs-agricultural productivity nexus.

Dimension	Description	No. of Studies
Conditions		
Knowledge (Know)	A reviewed article describes how ICTs help in disseminating agricultural knowledge and technologies (extension services)	22
Market (Mark)	A reviewed article describes how ICTs help farmers in accessing market information	17
Finance (Fin)	A reviewed article describes how ICTs help farmers in accessing financial services (credits and financial transactions)	5
Weather (Weat)	A reviewed article describes how ICTs help farmers in accessing weather and climate-related information	10
Outcome/s		
Productivity (Pro)	Whether or not a reviewed article shows that the use of ICT tools is linked with improved agricultural productivity, which in turn leads to farmers' livelihoods improvement	24

Source: Authors' formulation

Table 4. Descriptive statistics of conditions and outcomes.

Variable	Mean	Standard Deviation	Minimum	Maximum	N Cases	Missing
Knowledge	0.8916667	0.2763854	0.03	0.97	24	0
Market	0.6958333	0.4545297	0.03	0.97	24	0
Finance	0.2258333	0.4061164	0.03	0.97	24	0
Weather	0.4216667	0.4930066	0.03	0.97	24	0
Productivity	0.97	0	0.97	0.97	24	0

shows that none of the variables investigated was missing.

Table 5 presents the fuzzy set membership results of variables converted in the analysis using the fsQCA program's "calibrate" technique. In order to calibrate data that transformed the data into the log-odds metric with all values being between 0 and 1, we chose the values 0.95, 0.50, and 0.05 as the three thresholds (or breakpoints).

Analysis of the truth table

The truth table analysis is shown in Table 6 below. The truth table helps to differentiate between configurations that are the outcome's subsets and those which are not. The digits 1 and 0 represented the diverse corners of the vector space defined by the fuzzy set causal conditions. The results show a substantial consistency since none of the configurations (solutions) has a raw consistency level of less than 0.75, which indicates substantial inconsistency. This implies that ICTs significantly improve smallholders' farm productivity and livelihoods.

Analysis of necessary conditions

Table 7 shows the relevance of ICT tools in improving agricultural productivity and farmers' livelihoods. The main conclusions from the consistency column are as follows: ICTs are most impactful in disseminating knowledge and technologies and enhancing farmers' access to market information. 90% of the reviewed articles (0.9 consistency) describe the role of ICTs in disseminating agricultural knowledge and technologies (extension services). 70% of the reviewed articles (0.7 consistency) describe the role of ICTs in farmers' access to market information. These are the significant characteristics associated with improving agricultural productivity and, in turn, farmers' livelihoods improvement. The articles reviewed that describe the role of ICTs in farmers' access to financial services and climate-related information are 23% and 43% (0.2 and 0.4 consistency), respectively. These characteristics are not significantly crucial in improving agricultural productivity. However, the use of ICTs by smallholder farmers to access weather and financial service information remains a sufficient factor despite having low consistency.

Table 5. Fuzzy set membership variables by studies.

Study	Know	Mark	Fin	Weat	Pro
Angelo (2015)	0.97	0.97	0.03	0.03	0.97
Barakabitze et al. (2015)	0.97	0.03	0.03	0.03	0.97
Barakabitze et al. (2017)	0.97	0.97	0.03	0.97	0.97
Benard et al. (2020)	0.97	0.03	0.03	0.03	0.97
Isaya et al. (2018)	0.97	0.03	0.03	0.03	0.97
Karanja et al. (2020)	0.97	0.97	0.03	0.97	0.97
Kiberiti et al. (2016)	0.97	0.97	0.97	0.97	0.97
Krone et al. (2016)	0.97	0.97	0.03	0.03	0.97
Lwoga (2010)	0.97	0.97	0.03	0.03	0.97
Msoffe and Ngulube (2016)	0.97	0.03	0.03	0.03	0.97
Mtega and Msungu (2013)	0.97	0.97	0.97	0.03	0.97
Mtega and Ngoepe (2019)	0.97	0.97	0.97	0.97	0.97
Nyamba and Mlozi (2012)	0.97	0.97	0.03	0.97	0.97
Nyamba (2021)	0.97	0.97	0.03	0.03	0.97
Nyambo and Ligate (2013)	0.97	0.97	0.03	0.03	0.97
Okello et al. (2020)	0.97	0.97	0.97	0.03	0.97
Ortiz-Crespo et al. (2021)	0.97	0.97	0.03	0.03	0.97
Quandt et al. (2020)	0.97	0.97	0.03	0.97	0.97
Sanga et al. (2013)	0.97	0.97	0.03	0.03	0.97
Sanga et al. (2014)	0.97	0.97	0.03	0.97	0.97
Sanga et al. (2016)	0.97	0.97	0.97	0.97	0.97
Silvestri et al. (2021)	0.97	0.03	0.03	0.03	0.97
Mwalukasa et al. (2018)	0.03	0.03	0.03	0.97	0.97
Tumbo et al. (2018)	0.03	0.03	0.03	0.97	0.97

Table 6. Truth table.

Know	Mark	Fin	Weat	Number	Pro	Raw consist.
1	1	0	0	7	1	1
1	1	0	1	5	1	1
1	1	1	1	3	1	1
1	1	1	0	2	1	1
1	0	0	0	5	1	1
0	0	0	1	2	1	1

Note: Number refers to the number of cases displaying the combination of conditions. Raw consist refers to the extent of a consistent subset of membership in the outcome in that corner of the vector space

Table 7. Analysis of necessary conditions.

Outcome variable: Productivity		
Conditions tested	Consistency	Coverage
Knowledge	0.919244	1.000000
Market	0.717354	1.000000
Finance	0.232818	1.000000
Weather	0.434708	1.000000

Discussion

In order to increase smallholders' agricultural productivity, alleviate poverty and improve rural livelihoods in a country like Tanzania, where two-thirds of the population relies on traditional small-scale agriculture (Epaphra and Mwakalasya, 2017; Wineman et al., 2020; World Bank, 2019), integrating ICTs in agricultural transformation is essential (Lwoga, 2010). The access to and use of quality information through different ICT channels is crucial in informing rural smallholders on what to produce, how to grow, when to grow, where to grow and how to access markets. Studies show that the development of the ICT sector, mainly from the 2000s, has positively contributed to agricultural transformation, poverty reduction and farmers' livelihood improvements in rural Tanzania (Barakabitze et al., 2017; Lwoga et al., 2010). The leading ICT tools used in transforming agriculture include but are not limited to mobile phones, radios and televisions. These tools have helped create and disseminate agricultural knowledge and information services (Misaki et al., 2016). This part describes the role of ICTs in four aspects as analyzed in fsQCA above: knowledge, market, finance and weather. In addition to the secondary data sources, this part incorporates

information from in-depth interviews with a few smallholder farmers.

ICTs and dissemination of agricultural knowledge and technologies

The first condition tested in our study is the extent to which ICTs contribute to the farmers' access to agricultural technologies and knowledge (extension services). The results show high consistency (0.9), implying that most smallholder farmers use ICT tools (radios and mobile phones) to obtain agricultural knowledge and technologies. Literature shows that the mushrooming of ICTs in the early and late 2000s has vastly simplified the exchange of information between farmers and extension workers. ICTs have played a crucial role in disseminating indigenous and exogenous agricultural knowledge and skills in rural areas of Tanzania (Isaya et al., 2018; Lwoga et al., 2010). The traditional farmers-extension workers or farmer-farmer sharing of agricultural information only allows extension workers to visit farmers and share agricultural advisory information (Sanga et al., 2013). This conventional system in Tanzania faces many challenges, including the limited number of agricultural extension workers and resources, which limit farmers' access to extension services (Karanja et al., 2020; Tumbo et al., 2018). ICTs, mainly radios and mobile phones, have appeared to help break the gap of the limited number of extension workers as farmers can now access agricultural knowledge and technologies through ICT tools. By reflecting on "an impact-driven, radio-based extension service delivery system" which aims at helping extension workers to reach more rural smallholder farmers of Tanzania, many smallholder farmers were reported to change their farming practices through experiences shared by extension workers and their fellow farmers and hence increase agricultural productivity (Sanga et al., 2013).

Apart from radios, mobile phones have made it easy for smallholder farmers to access extension services. Mobile phones have allowed extension workers to reach the farmers without physical presence. Farmers can either call the extension service workers directly or use Short Message Service (SMS) to communicate with the extension workers (Karanja et al., 2020). According to many studies (Karanja et al., 2020; Ortiz-Crespo et al., 2021), this approach has been appreciated by many farmers in Tanzania due to its accessibility, affordability, and flexibility. Through mobile phones, farmers can access information on farm crop diseases, training schedule for farmers and information on researchers' field visits or "farm walks" (Barakabitze et al., 2017). One of the smallholder farmers who participated in our in-depth interviews described how he uses his phone to access agricultural information, saying:

> "My phone means everything to me. I can call a government extension agent or my fellow farmers to ask for help when I have an issue with agriculture. When my tomatoes were being attacked by *kantangaze* [*Tuta absoluta*] in 2017, I called an extension agent, and he suggested a type of pesticide that I should use, and it worked well" (Interview with a horticultural farmer from Iringa region, 2022).

Mobile phone extension services have advanced to the point where automated messaging services have been developed, allowing farmers to ask for agricultural advice through messages and receive responses in the form of pre-recorded messages. In their experiment in southern parts of Tanzania, for example, Ortiz-Crespo et al. (2021), using a "User-Centred Design", created a new digital information service called *Ushauri,* which enabled farmers to access a set of pre-recorded messages. This automated hotline enables farmers to send messages and be responded to by the extension agents through an online platform. It is similar to other agricultural advisory systems used in Tanzania. One of them is *UshauriKilimo* (Agro-Advisory), a system that allows farmers to ask questions via SMS or online for those with access to internet services (Sanga et al., 2013). *UshauriKilimo* was designed by the Sokoine University of Agriculture in collaboration with the Kilosa district council.

The network operators have also aided in disseminating agricultural knowledge and technologies by establishing Agricultural Value-Added Services (Agri VAS). Nevertheless, three network operators are reported to include extension services in their customer service systems. Tigo Tanzania was the first to launch extension services in 2012. The company launched the so-called *TigoKilimo* (TigoAgriculture), which aims to offer "relevant, timely and actionable information via mobile phones to farmers in Tanzania across three domains: agronomic practices on major crops, market price information, and weather forecasts" (Kante et al., 2016). Other agricultural information obtained through this approach includes

"soil management, pest control methods and information on livestock knowledge and bird flu" (Kante et al., 2016). Two years after its official launch in December 2012, *TigoKilimo* had almost 400,000 registered users. Other communication companies also offer similar services, including Zantel telecom operator, which launched *Z-Kilimo* in 2013. Recently, Vodacom Tanzania launched its Agri VAS called *M-Mkulima*. All these services help smallholder farmers access agriculture information and increase agricultural productivity.

ICTs and access to market information

The second condition tested in our study was how ICTs help farmers access agricultural market information. Though the results from the analysis show moderate consistency (0.7), empirical studies support that ICTs, particularly mobile phones help Tanzania's smallholder farmers to access agricultural market prices (Okello et al., 2020). Although the majority of farmers prefer to access market information through farmer-to-farmer communication, relatives, intermediaries, and local traders (Eskia, 2019; Mwakaje, 2010), there is a significant number of farmers who use ICT tools, primarily mobile phones (Barakabitze et al., 2015, 2017), and radios (Isaya et al., 2018) to access market information. By using mobile phones, for example, farmers can call or use SMS to communicate with different buyers and compare the price of their crops from one place to another or from one buyer to another (Okello et al., 2020). This information increases the bargaining power (Kiberiti et al., 2016; Krone et al., 2016) and helps farmers sell the produce at a high price. A farmer who regularly takes his produce to the market confirmed the use of mobile phones in accessing market information saying:

> "Before I had this phone, it was difficult for me to access the timely market price, and I always used to sell my produce at a lower price when I went to the market. Nowadays, thanks to the use of mobile phones, I can quickly access market information for various regions of the nation and choose whether or not to sell my produce by calling friends or other business people and asking them for the current price" (Interview with a smallholder farmer from Ruvuma region, 2022).

ICTs assist smallholder farmers in gaining access to information about global, regional and local markets. Farmers use ICTs to take advantage of opportunities to directly or indirectly sell their produce in the global and regional markets and fetch a higher price when some nations experience protracted droughts or pest attacks. One of our respondents affirmed:

> "ICTs greatly assist me in gaining access to market information, especially related to international markets. I learn which countries will have a food shortage through information from radio and television, and I then get ready so that I can sell my products for more money. I will just store my produce and wait for the international markets to open when I learn that information" (Interview with a smallholder farmer from Arusha region, 2022)

Krone et al. (2016) also reported that ICTs, particularly mobile phones, enabled smallholder farmers to access timely price information, a situation that could be impossible without using mobile phones. Nevertheless, the use of ICT in accessing the market by rural smallholder farmers is significantly influenced by the quantity of crops produced, farmers' level of income, level of education, type of crop marketed and farmers' gender (Mwakaje, 2010). Studies also suggest that farmers who use ICTs obtain higher prices than their counterparts (Krone et al., 2016). Besides, smallholder farmers use ICT tools to obtain information on the price of agricultural inputs from the market (Barakabitze et al., 2017). ICTs also help farmers to access complete market information and avoid the risk of being deceived by intermediaries who always accumulate profit due to farmers' lack of access to complete market information (Kiberiti et al., 2016; Sife et al., 2010).

ICTs and financial services

The third condition that we analyzed is the linkage between ICTs, access to financial services and agricultural productivity. Though the results from the analysis show less consistency (0.2), ICTs' role in farmers' access to financial services cannot be underestimated. Credits help smallholder farmers to get financial capital for agricultural investments. In many rural settings, access to credit information among smallholder farmers is low due to limited interaction with the financial institutions primarily situated in urban areas. Many credits intended to benefit the rural smallholder farmers in Tanzania have not reached the targeted population due to the lack of access to complete information. However, with the help of radios and mobile phones, smallholder farmers can access information about institutions that provide loans for agriculture farmers

(Barakabitze et al., 2017). ICT tools, mainly mobile phones, also help in financial transactions. However, this depends on the buyer-seller levels of trust as those who trust the buyers increase the likelihood of using mobile phones in business transactions (Okello et al., 2020), while other new technologies like radios and T.V. serve as the source of information. Our interviews with the respondents revealed that mobile phones have made money transactions easier for smallholder farmers, decreasing the risk of going to the market to collect money from customers. This is made possible because transportation between rural and urban areas is becoming simple and affordable, and that rural infrastructure, particularly roads, is continually improving. One of our respondents confirmed this information saying:

> "These days, I do not always go to town to sell my crops. I can communicate with the buyer, and once we agree on a price, I send him the produce, and he will pay me the money through M-Pesa or Tigopesa [M-Pesa and Tigopesa are two among the most popular mobile money transaction services in Tanzania]" (Interview with a smallholder farmer from Iringa region, 2022).

ICTs and access to weather information

The last condition tested in this study was the nexus between ICTs and access to weather and climate-related information with agricultural productivity and improvement of farmers' livelihoods, where the 0.4 consistency level was obtained. Smallholder farmers in Tanzania are not exceptional from the changing weather condition and the effects of global climate change. Acquiring the necessary knowledge and skills to cope or survive amidst these challenges is crucial for the future of smallholder farmers. Tanzanian smallholder farmers face "delayed onset of rains, poor rainfall distribution throughout the cropping season, and extreme weather conditions, such as droughts and floods" (Tumbo et al., 2018). However, given the scarcity of extension workers, ICT tools are increasingly being recognized as alternative strategies for disseminating information about weather and climate change, as well as how to build resilience (Barakabitze et al., 2017). ICTs, particularly mobile phones and radios, have helped narrow the gap between extension service agents and smallholder farmers, particularly in climate change adaptation (Tumbo et al., 2018). Many radio stations provide weather broadcasting every day, which helps smallholder farmers to plan for the planting season. A smallholder farmer who participated in the interview affirmed this:

> "Every day, I listen to weather reports on radio stations, including TBC [Tanzania Broadcasting Corporation]. According to the weather broadcasts, I can determine whether the rainy season will be delayed and what crops I should grow. In order to prevent the loss, I choose to grow crops that can withstand drought and mature quickly" (Interview with a smallholder farmer from Morogoro region, 2022).

When asked about the accuracy of weather information from radios, our respondent added:

> "I see the provision of weather information nowadays is highly improved, and the information is always accurate. Media outlets are making every effort to present accurate information, which differs from a few years ago, for, say, 75 or 80% of the information is accurate. Today, however, believe them when they tell you that the same thing will occur. I think the tools used to gather weather data have possibly been improved" (Interview with a smallholder farmer from Morogoro region, 2022).

For farmers to succeed in production, access to information about the weather and climate continues to be one of the most crucial factors. This aids farmers in deciding what to produce and how to produce it in light of the information. Farmers might choose to grow crops that are drought resistant and ready to harvest early, for instance, when the weather is harsh and the rainy season is brief. Numerous ICT-based initiatives, such as "the Upscaling Technologies in Agriculture through Knowledge and Extension (UPTAKE)" program run by the FAO in Tanzania's Southern Highlands (FAO, 2018; Karanja et al., 2020), have greatly aided maize farmers in reducing their exposure to weather- and climate-related risks.

ICTs, agricultural productivity and farmers' livelihood improvement

ICTs use is increasingly making a difference in the lives of smallholder farmers in developing nations, particularly in SSA (Asenso-Okyere and Mekonnen, 2012; Deichmann et al., 2016; Mapiye et al., 2021; Min et al., 2020). However, the crucial query is: How do ICTs assist smallholder farmers in raising agricultural productivity? Two perspectives on how

ICTs aid smallholder farmers in boosting agricultural productivity are offered by the World Bank. On the one hand, ICTs enable smallholder farmers to use inputs and resources sustainably and environmentally, adapt to threats to productivity, and match cropping practices with climatic trends (World Bank, 2017: 99), increasing agricultural productivity and improving farmers' livelihoods. The literature reviewed in this article also confirms this by showing how smallholders use ICTs to change farming practices due to access to complete information on how to grow crops and how to cope with agricultural threats like pests, diseases and climate-related disasters (Barakabitze et al., 2017; Karanja et al., 2020; Mwalukasa, 2013; Silvestri et al., 2021). The respondents further supported this in our in-depth interviews, saying that using ICTs allowed them to adopt new farming methods, which increased agricultural productivity. On the other hand, by adjusting policies that allow ICTs to collect data that predict food supplies and policies that target social programs or promote yield technologies, ICTs, particularly at the national level, help smallholders increase agricultural productivity (World Bank, 2017: 99).

According to empirical research from Tanzania, various agricultural-related radio programs and mobile phone communications are changing farmers' livelihoods and helping smallholder farmers produce more food and cash crops (Karanja et al., 2020; Mtega and Msungu, 2013). A study by Quandt et al. (2020) in four rural Tanzanian communities found a high correlation between mobile phone use and increased agricultural productivity among farming households. According to the study's additional findings, 67% of respondents said using a mobile phone increased agricultural profits, while 50% and 47% said it decreased expenses and time commitments. This finding is consistent with Sife et al. (2010) who discovered that ICTs assist smallholder farmers in Tanzania's rural areas by reducing travel expenses for information search purposes. Smallholder farmers who once had to travel great distances in search of agricultural information no longer do so because they have access to radios and mobile phones. They, therefore, use time and resources that would be used to travel a long distance to improve agricultural productivity and improve their livelihoods.

Agricultural productivity was also reported to be increased due to the farmer's ability to control pests and diseases (Karanja et al., 2020) and avoid on-farm loss. In the FAO UPTAKE project carried out in the Southern Highlands of Tanzania, for example, farmers who received an early-warning SMS on pest attacks reported having increased productivity as they managed to control pests on time by using recommended pesticides (FAO, 2018). Besides, Barakabitze et al. (2017) found that using ICTs is highly associated with improving agricultural productivity (Table 7) as farmers change their traditional farming practices and adopt modern ones. Comparatively, farmers who do not employ technologies gain lower yields than their counterparts who use ICTs in accessing agricultural information. Nevertheless, their study emphasized the importance of farmer-researcher participation in designing suitable ICT tools that could help farmers to increase crop yields. When agricultural researchers were asked about the role of ICTs in improving agricultural productivity, more than 90% agreed that using ICTs is highly associated with increased agricultural productivity among smallholder farmers (Barakabitze et al., 2017). Comparatively, farmers who integrate ICTs and other technologies in their farming obtain higher yields compared to those who do not.

In sum, raising agricultural productivity is a requirement for raising the standard of living for rural farming households. However, the main barrier to agricultural transformation and increased productivity for most smallholder farmers in many developing countries is access to timely and pertinent agricultural information. ICTs assist in educating farmers about better farming practices and market demands due to the dearth of government extension service agents, which increases agricultural productivity and improve farmer livelihoods. The more the farmers use ICT tools in communicating agricultural information, the more they increase farming productivity and improve their livelihoods.

Conclusion and recommendations

Building on secondary data sources and in-depth interviews, this paper has explored the role of ICTs in promoting agricultural productivity and improving farmers' livelihood in Tanzania. The study uses fsQCA to analyze conditions that dictate smallholders' reliance on ICT tools to transform agricultural practices, increase productivity and improve their livelihoods. It has been observed that ICTs play a significant role in transforming the agricultural sector and rural livelihoods in Tanzania, mainly by

helping access agricultural knowledge and technologies (extension services) and providing market, weather, and financial service information to smallholder farmers. The search for agricultural knowledge forces most smallholder farmers to opt for ICT tools as their alternative source of agricultural information following the limited number of public extension service agents. As our analysis shows, the search for agricultural knowledge has a high consistency level (0.9) as compared to the market (0.7), weather (0.4), and finance (0.2).

ICTs help address the limited number of advisory and extension service workers and help the few extension agents serve many farmers within a short period. With the increasing mobile phone access and use, for example, most farmers in Tanzania use mobile information to access agriculture information more than other ICT tools like radio, television, and the internet. Convenience in getting agricultural information, communication and money transfer make it easier for smallholder farmers to use mobile phones than any other ICT tools. Besides that, a mobile phone is a multipurpose tool that can be used as a radio and a device that could help to access information through internet services. However, in some cases, access to and use of mobile phones does not necessarily mean the smallholders' familiarity with the existing mobile agro-advisory services. This implies that capacity building for the farmers on the linkage between mobile phone usage and access to agro-based information needs to be strengthened.

Radio has also been reported to play a great role in agricultural development in Tanzania. With the rapid surge of local radio stations (those covering small areas like a township, district, or region/province) as a result of market liberalization, locally based agricultural-related information has been increasingly communicated to and utilized by the local farmers through extension workers or farmer-farmer sharing of agricultural experience and success stories. Compared to other ICT tools, radios, particularly community radio stations, can be used to disseminate agricultural information needed in a specific locality and help smallholder farmers improve agricultural practices. The application of radios in accessing agricultural information is the most cost-effective compared to other ICT tools. However, it is vivid that no one size fits all. The combination of different ICT tools and other mechanisms in communicating agricultural information would be of great importance to ensure efficiency and effectiveness in disseminating agricultural information, transforming smallholder agriculture and the livelihoods of smallholder farmers. The study situates the nexus between the use of ICT tools, increased agricultural productivity and farmers' livelihood outcomes in the wider context of Africa and other developing countries that share similar social, economic, political and technological characteristics like that of Tanzania.

This paper suggests that Tanzania should strengthen ICT infrastructure in rural settings and build capacity for smallholder farmers to link ICT with agricultural transformation. By strengthening ICT infrastructure, for example, smallholder farmers will increase the ability to obtain timely and appropriate agricultural information and widen the market through online marketing platforms (e-commerce), which are booming in many parts of developing countries. In this case, the agricultural extension department from the Ministry of Agriculture should work closely with telecom, broadcasting companies and other stakeholders to strengthen and initiate more appropriate ICT services targeting smallholder farmers. We also recommend increasing the number of community and local radio stations that highly focus on disseminating agriculture knowledge to the local smallholder farmers and hence help to improve agriculture, lift the marginalized rural population out of poverty and improve their livelihoods. Since agriculture is the mainstay of the country's economy, we also recommend an increasing number of sessions related to agriculture on national radio and T.V. stations. These sessions should cover issues related to agriculture knowledge and technologies, marketing, weather and climate, and information on accessing agricultural credits. Contents and presentations on agro-advisory knowledge in these radio and T.V. sessions should be offered by professionals, including extension officers, academics, market professionals, farmers, and others who are essential in the agricultural value chain.

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Appendix

Appendix A: In-depth interview guide for the smallholder farmers

Part A. Respondent's Demographic Profile					
Respondent's Name (Not Mandatory)					
Gender		M	F	Age	
Location	Region			District	
Educational level		No formal education			Certificate/Diploma
		Primary education			Bachelor's Degree
		Secondary education			Master's degree and above
Agricultural activities involved in		Crop farming (Rainfed)			Agroforestry
		Horticulture			Aquaculture
		Livestock keeping			Others:
		Beekeeping			
Interview date					

Part B. Interview Content

This research aims to understand how Information and Communication Technologies (ICTs) mainly radios and mobile phones help smallholder farmers to increase agricultural productivity and improve their livelihoods in Tanzania. Your participation in this study is voluntary and you can respond either in English or Swahili language.

Utafiti huu umelenga kuelewa jinsi Teknolojia ya Habari na Mawasiliano (TEHAMA), hasa redio na simu, zinavyowasaidia wakulima wadogo wa Tanzania kuongeza uzalishaji na kuboresha maisha yao. Ushiriki wako ni wa hiari na unaweza kujibu maswali kwa kutumia lugha ya Kiingereza ama Kiswahili.

1. What kind of ICT tools do you mostly use to access agricultural information and why?
1. Ni aina ipi ya TEHAMA unaitumia zaidi ili kupata taarifa zinazohusu kilimo na kwa nini?

2. What factors make you use radios and mobile phones in accessing agricultural information?
2. Ni sababu zipi zinakufanya utumie redio na simu ili kupata habari za kilimo?

3. How do ICT tools help you to access the following information?
   a. Agricultural knowledge and technologies
   b. Agricultural market information
   c. Financial services
   d. Information on weather and climate change

3. Ni kivi TEHAMA inakusaidia kupata taarifa zifuatazo?
   a. Taarifa kuhusu maarifa na teknolojia ya kilimo
   b. Taariza za masoko
   c. Taarifa za kifedha
   d. Taarifa kuhusu mabadiliko ya hali ya hewa na tabia ya nchi

4. In your experience, how ICTs have directly or indirectly helped you to increase agricultural productivity and improve your livelihoods?
4. Kwa uzoefu wako, ni kwa namna gani TEHAMA imekusaidia kuongeza uzalishaji na kuboresha maisha yako?

5. What are the challenges to the effective use of ICTs to increase agricultural productivity and improve your livelihoods and how could those challenges be addressed?
5. Ni changamoto zipi zinazopunguza ufanisi wa matumizi TEHAMA kama nyenzo ya kuongeza uzalishaji na kuboresha maisha yako na namna gani zinaweza kutatulika?

6. Would you like to share any other valuable information that you think is helpful to this study?
6. Je, engependa kutoa taarifa nyingine za ziada ambazo unadhani zitasaidia katika utafiti huu?

Thank you for your participation *Asante kwa ushiriki wako*

Appendix B: Step-by-step Calibration of fsQCA
Raw data table

CaseID	Knowledge	Inputs	Market	Finance	Weather	Agricultural Productity	
Angelo (2015)	1	0	1	0	0	1	1
Barakabitze et al. (2015)	1	1	0	0	0	1	1
Barakabitze et al. (2017)	1	1	1	0	1	1	1
Benard et al. (2020)	1	0	0	0	0	1	1
Isaya et al. (2018)	1	1	0	0	0	1	1
Karanja et al. (2020)	1	1	1	0	1	1	1
Kiberiti et al. (2016)	1	1	1	1	1	1	1
Krone et al. (2016)	1	1	1	0	0	1	1
Lwoga (2010)	1	0	1	0	0	1	1
Msoffe and Ngulube (2016)	1	0	0	0	0	1	1
Mtega and Msungu (2013)	1	1	1	1	0	1	1
Mtega and Ngoepe (2019)	1	1	1	1	1	1	1
Mwalukasa et al. (2018)	1	0	0	0	1	1	1
Nyamba & Mlozi (2012)	1	1	1	0	1	1	1
Nyamba (2021)	1	0	1	0	0	1	1
Nyambo and Ligate (2013)	1	0	1	0	0	1	1
Okello et al. (2020)	1	1	1	1	1	1	1
Ortiz-Crespo et al. (2021)	1	0	1	0	0	1	1
Quandt et al. (2020)	1	1	1	0	1	1	1
Sanga et al. (2013)	1	1	1	0	0	1	1
Sanga et al. (2014)	1	0	1	0	1	1	1
Sanga et al. (2016)	1	1	1	1	1	1	1
Silvestri et al. (2021)	1	0	0	0	0	1	1
Tumbo et al. (2018)	1	0	1	0	1	1	1

Calibration process

compute: Know = calibrate(Knowledge,0.95,0.50,0.05)
compute: Mark = calibrate(Market,0.95,0.50,0.05)
compute: Fin = calibrate(Finance,0.95,0.50,0.05)
compute: Weat = calibrate(Weather,0.95,0.50,0.05)
compute: Pro = calibrate(Productity,0.95,0.50,0.05)

Cases with greater than 0.5 membership

Cases with greater than 0.5 membership in the term Know*Mark: Angelo2015 (0.97,0.97), Barakabitzeetal2017 (0.97,0.97), Karanjaetal2020 (0.97,0.97), Kiberitietal2018 (0.97,0.97), Kroneetal2016 (0.97,0.97), Lwoga2010 (0.97,0.97), MtegaMsungu2013 (0.97,0.97), MtegaNgoepe2019 (0.97,0.97), NyambaMlozi2012 (0.97,0.97), Nyamba2021 (0.97,0.97), NyamboLigate2013 (0.97,0.97), Okelloetal2020 (0.97,0.97), OrtizCrespoetal2021 (0.97,0.97), Quandtetal2020 (0.97,0.97), Sangaetal2013 (0.97,0.97), Sangaetal2014 (0.97,0.97), Sangaetal2016 (0.97,0.97)

Cases with greater than 0.5 membership in term Know*~Fin*~Weat: Angelo2015 (0.97,0.97), Barakabitzeetal2015 (0.97,0.97), Benardetal2020 (0.97,0.97), Isayaetal2018 (8.97,0.97), Kroneetal2016 (0.97,0.97), Lwoga2010 (0.97,0.97), MsoffeNgulube2016 (0.97,0.97), Nyamba2021 (0.97,0.97), NyamboLigate2013 (0.97,0.97), OrtizCrespoetal2021 (0.97,0.97), Sangaetal2013 (0.97,0.97), Silvestrietal2021 (0.97,0.97)

Cases with greater than 0.5 membership in term ~Know*~Mark*~Fin*Weat: Mwalukasaetal2018 (0.97,0.97), Tumboetal2018 (0.97,0.97)

*** ERROR(Quine-McCluskey): The 1 Matrix Contains All Configurations. ***

Algorithm: Quine-McCluskey

— PARSIMONIOUS SOLUTION —

frequency cutoff: 2

consistency cutoff: 1

****

Set coincidence

coincidence(Know,Mark,Fin,Weat) = 0.152062
coincidence(Know,Mark,Weat) = 0.353952
coincidence(Know,Mark,Fin) = 0.253271
coincidence(Know,Fin,Weat) = 0.152062
coincidence(Mark,Fin,Weat) = 0.190527
coincidence(Know,Mark) = 0.780374
coincidence(Know,Weat) = 0.353952
coincidence(Mark,Weat) = 0.443488
coincidence(Know,Fin) = 0.253271
coincidence(Mark,Fin) = 0.324551
coincidence(Fin,Weat) = 0.295

****

SUBSET/SUPERSET ANALYSIS

****

Outcome: Pro

Subset/superset analysis

****

SUBSET/SUPERSET ANALYSIS

****

Outcome: Productity

	Raw consistency	Coverage	combined
Finance	1.000000	0.208333	0.454148
Finance*Weather	1.000000	0.125000	0.351781
Knowledge	1.000000	0.916667	0.952628
Knowledge*Finance	1.000000	0.208333	0.454148
Knowledge*Finance*Weather	1.000000	0.125000	0.351781
Knowledge*Market	1.000000	0.708333	0.837407
Knowledge*Market*Finance	1.000000	0.208333	0.454148
Knowledge*Market*Finance*Weather	1.000000	0.125000	0.351781
Knowledge*Market*Weather	1.000000	0.333333	0.574456
Knowledge*Weather	1.000000	0.333333	0.574456
Market	1.000000	0.708333	0.837407
Market*Finance	1.000000	0.208333	0.454148
Market*Finance*Weather	1.000000	0.125000	0.351781
Market*Weather	1.000000	0.333333	0.574456
Weather	1.000000	0.416667	0.642262