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# The role of information and communication technologies-based extension in agriculture: application, opportunities and challenges

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## ABSTRACT

Limited access to information about new technologies is a major barrier to agricultural productivity. To bridge this information gap, agricultural extension services increasingly use Information and Communication Technologies (ICTs) to provide timely and actionable information to farmers. This systematic review analyses evidence from 49 studies examining the impact of ICT interventions including mobile apps, SMS messaging, educational videos, and voice calling services on awareness, agricultural practices adoption, yields, and income. The review reveals that 76% of studies reported increased adoption of good agricultural practices, 60% demonstrated improved awareness, 74% indicated higher yields, and 68% observed enhanced incomes. Cereals, particularly maize, were the most studied crops, featuring in 52% of the studies. The success of the ICT interventions depends on well-designed messaging, adequate user training, and integration with complementary interventions. While ICTs demonstrate substantial potential to advance agricultural development outcomes, their success requires customization to local contexts, capacities, and cropping systems.

## KEYWORDS

ICTs; e-extension; mobile phones; technology adoption; yield; income

## 1. Introduction

Access to information on agricultural technology is a critical determinant of agricultural productivity. Farmers need relevant and timely information and knowledge to effectively plan and adopt farming practices (Masuki et al., 2010). Smallholder farmers need access to information about agricultural technologies to make informed adoption decisions. Traditionally, farmers have relied on research institutions, extension agents, and NGOs for information about new technologies. However, the traditional extension system is ridden with human resources challenges, a lack of accountability, and overly generalized messages (Davis, 2020). Furthermore, face-to-face extension campaigns often struggle to reach farmers in remote areas and are significantly constrained during crises that limit physical contact, such as the COVID-19 pandemic.

The rise of information and communication technologies (ICTs) such as the Internet and mobile phones offers innovative solutions to overcome these hurdles (Emeana et al., 2020). ICTs have resulted in the emergence of digital advisory services, commonly called e-extension, ICT-based

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extension, or ICT for agriculture. These platforms provide farmers with timely and site-specific advice on agricultural practices, input use, crop planting dates, local weather predictions, market prices, and access to social networks (Emeana et al., 2020; Evans, 2018).

The growing availability of ICT applications has led to significant growth in digital extension services. Observational and experimental studies have evaluated the impacts of these tools on outcomes such as knowledge, awareness, adoption of certain technologies, choice of market channel, health, profit, and income (see for example Aker et al., 2016; Arouna et al., 2021; Kiiza & Pederson, 2012). Recent studies have further expanded the scope of ICTs in agriculture, exploring their roles in data management systems (Mushi et al., 2023), accountability tools (Namyenya et al., 2022), and the factors affecting the adoption of actual ICT tools (Smidt & Jokonya, 2022). Despite these efforts, a comprehensive synthesis of evidence of ICT's impact across different outcomes remains needed.

This study aims to bridge this gap by systematically reviewing the role of ICTs in agriculture, focusing on four key outcomes: awareness, adoption of agricultural technologies, yield, and income. These outcomes are the most frequently studied pathways for ICTs impact on agriculture (Ayim et al., 2022). Our analysis includes studies that describe and estimate the relationship between ICT use and these outcomes. This study provides a comprehensive review to inform policies and practices, leveraging ICTs for agricultural development. To our knowledge, this is the first systematic review to consolidate results from different disciplines, primarily economics, and includes studies evaluating the relationship between ICT use and these outcomes.

This study builds on previous reviews of ICTs in agriculture. Aker (2011) highlighted the potential of ICT tools (voice, text, Internet, and mobile money transfers) and proposed randomized controlled trials (RCTs) to rigorously evaluate their impact. Since then, several RCTs have been conducted, providing robust evidence. Zhang et al. (2016) reviewed ICT-based information dissemination models in China to share knowledge and experiences in applying emerging ICTs to disseminate agricultural information to farmers. They identified seven models that improve economic, social, and environmental sustainability. Nakasone et al. (2014) examined ICTs in agriculture markets, and found positive impacts at the macro level, but mixed impacts on income at the micro level. Recently, Abate et al. (2023) reviewed ICT tools for market participation and identified barriers to scaling. Ayim et al. (2022) conducted a scoping review of ICT use in African agriculture, examining tools developed, countries using them, study frameworks, and challenges. Essentially, the application of digital communication technology in agriculture is vast and developing rapidly, and there is a need to evaluate its impact on smallholder farmers (Emeana et al., 2020). This review differs from previous studies in several ways. First, we focus on four primary outcomes: awareness, adoption, yields, and income, providing a broader perspective than reviews that center only on income or market participation. Second, we investigate additional dimensions, such as the most common types of ICTs, the technologies they promote, the crops they target, and the countries where they are studied. Third, we include recent RCTs studies that have emerged since earlier reviews and provide more rigorous evidence. By synthesizing findings across multiple studies and contexts, this review aims to provide a more comprehensive understanding of the opportunities and challenges associated with the use of ICTs in agricultural extension and development.

## 2. Methodology

### 2.1. Systematic review

We employ a systematic review methodology to comprehensively assess the impact of ICT-based extension on smallholder development outcomes. By aggregating findings from diverse studies, systematic reviews can provide robust evidence to inform policy and practice (Mallett et al., 2012). This approach allows us to identify patterns, gaps, and contextual factors that shape the effectiveness of ICTs in agriculture, advancing our understanding of their role in development. This systematic review also enables us to synthesize insights across various ICT tools, crops, and geographies, offering a

broad perspective on the state of knowledge in this domain. By focusing on four key outcomes - awareness, agricultural practices (which we also refer to as technology adoption, i.e. not ICT adoption) adoption, yields, and income—our study provides a nuanced understanding of the multifaceted effects of ICT-based interventions. This methodological approach contributes to the field by offering a structured framework for assessing the effectiveness of ICTs in agricultural development, thereby informing evidence-based policy and practice.

## **2.2. Criteria for inclusion**

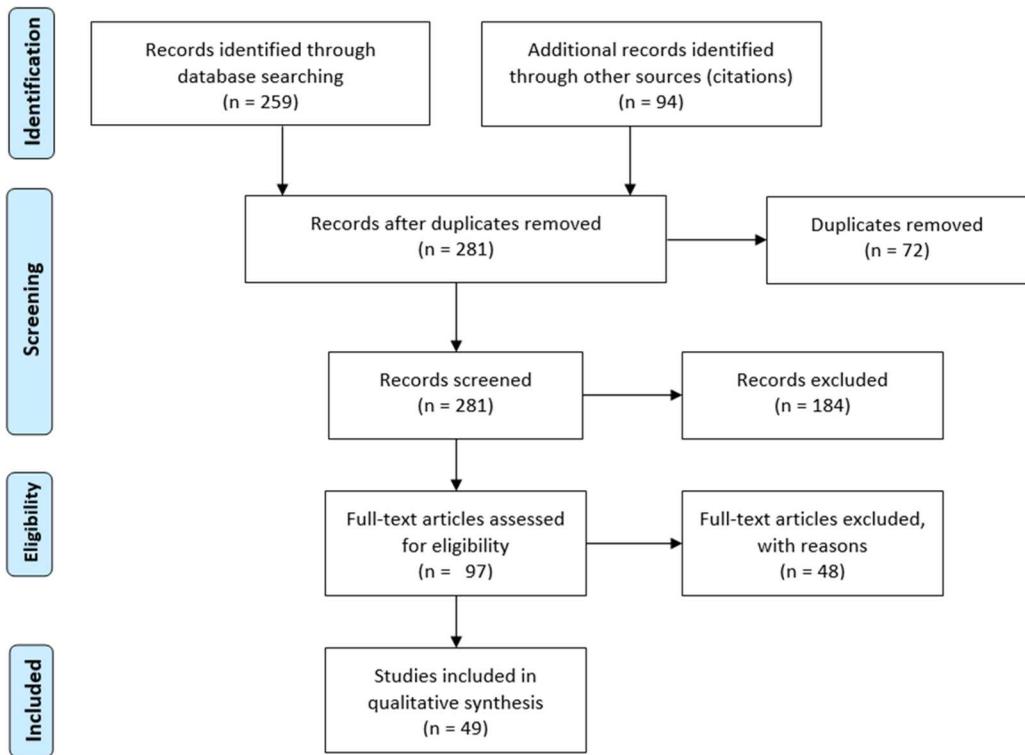
This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist (Page et al., 2021). The search for literature was conducted from June 2022 to July 2022 by two investigators in three databases: Google Scholar, IDEAS/Repec, and AgEcon Search. Articles retrieved were from the period 2010 to 2022. We considered all articles with empirical evidence of ICT's impact on the four outcomes. We focused on studies that reported the impact of ICT-based extension services on the four outcomes in developing countries.

The four major outcomes of interest were (i) awareness/knowledge, (ii) adoption of agricultural technologies because of ICT-based extension, and (iii) crop yield and/or (iv) income/profit from using ICTs. Our criteria were inclusive of only primary research studies published in peer-reviewed journals and in the English language. We excluded articles that did not report empirical evidence on any of the four outcomes: for example, studies estimating the impact of ICTs on the choice of marketing channel or nutrition. We excluded all papers that were not reporting the use of ICT, not evaluating the impact of ICT, not on agriculture, not in developing countries, not on crops/fruits/vegetables, and not on farmers.

Our search terms were 'Farmers' AND 'Digital Agricultural Systematic' OR 'E-extension' OR 'ICT for agriculture' OR 'Applications' OR 'SMS' OR 'Phone' OR 'Internet' OR 'Website' AND 'Crop yield' OR 'Income' OR 'Adoption' OR 'Awareness' OR 'Knowledge.' However, because of the lack of standardization of the technical terms in this field, most of the literature was obtained through a snowball approach by checking the cited papers from other papers.

## **2.3. Article selection**

Eligible articles were selected based on an assessment of the titles. We then created a database of the selected articles ( $n = 281$ ) using the Zotero reference manager software. We then reviewed the abstracts of all articles to identify the full-text articles included in the systematic review. We also screened references and bibliographies of articles that met the criteria, and in total, 97 articles were found eligible for full-text review. We then reviewed these articles and removed 48 articles that did not meet the criteria. These were eliminated because they were mostly qualitative and did not report on the impact of ICTs. We then commenced data extraction to obtain the final list. Some articles were also removed at this stage because they did not meet the criteria, as they did not report the outcomes of interest, and some were not implementing ICT but agricultural technology. After screening, 49 articles were included in the review. Importantly, our review includes a significant number of RCTs published since Aker's (2011) call for more rigorous research designs. Of the 49 studies included, 23 are RCTs, representing a substantial shift in the methodological approach to studying ICT impacts in agriculture. This increase in RCTs allows for more robust causal inferences and addresses many of the limitations of earlier observational studies. In our analysis, we pay particular attention to the findings from these RCTs, as they provide stronger evidence for the causal effects of ICT interventions on our outcomes of interest. The selection criteria and steps taken to identify articles are shown in The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) flow diagram (Figure 1). Compared to previous reviews, our review includes substantially



**Figure 1.** PRISMA diagram showing the flow of the systematic search and selection of articles for systematic review. After the initial search yielded more than 280 articles, the selection criteria were applied, which reduced the number of papers used for review to 49.

more papers with the most recent ones using randomized controlled trials, meaning the identification of the impact is much stronger.

## 2.4. Analysis of articles

To extract relevant information from each paper, we used a data extraction table as a guide. The table was prepared in Microsoft Excel, and two independent research assistants extracted and summarized the data from the selected articles; the two spreadsheets were combined into one table (see supplementary file 1). This table has the following sections: authors, study title, year of publication, country of study, type of agriculture, type of ICT, methodology, study sample size, sample characteristics, agricultural technology intervention being promoted, the outcome of concern, and impact of the ICT intervention.

For quality assessment of chosen articles, we used the mixed methods appraisal tool (MMAT) version 2018 (Hong et al., 2018) to assess the relevance of selected papers, adequacy, methodology, study design, data collection, data analysis, presentation of findings, discussion, and conclusions. The MMAT was used because it clarifies the essential aspects of quantitative descriptive and randomized control studies, thereby identifying the risk of bias for each outcome across individual studies.

## 2.5. Theoretical background

This study is situated within the broader literature on ICTs and development, which examines how digital technologies can contribute to economic, social, and human development outcomes (Mamba

& Isabiry, 2015; Roztocki et al., 2019; Smidt & Jokonya, 2022). A key theoretical lens in this field is the capability approach (CA), which emphasizes the role of technology in expanding people's freedom and opportunities to lead the lives they value (Kleine, 2013; Sen, 2001). In the context of agriculture, ICTs can enhance farmers' capabilities by improving access to information, knowledge, and markets, ultimately contributing to increased productivity, income, and well-being (Aker et al., 2016; Deichmann et al., 2016). We rely on Kleine's Choice Framework (Kleine, 2013) to analyze the impact of ICT-based extension on smallholder farmers' development outcomes. The Choice Framework is rooted in Sen's capability approach (Sen, 2001) and emphasizes the role of ICTs in expanding people's choices and agency, which are central to the development process. It considers four dimensions of choice: existence of choice, sense of choice, use of choice, and achievement of choice (Kleine, 2013).

In the context of agricultural extension, ICTs can contribute to the existence of choice by providing farmers with access to a wider range of information, knowledge, and services that were previously unavailable or difficult to obtain (Aker et al., 2016; Deichmann et al., 2016). For example, mobile phone-based services can offer timely and localized information on weather, market prices, and farming practices, thereby expanding farmers' options for making informed decisions (Cole & Fernando, 2012; Fafchamps & Minten, 2012).

However, the mere existence of choice does not necessarily translate into a sense of choice or the actual use of choice. Factors such as digital literacy, sociocultural norms, and power dynamics can influence farmers' perception and ability to take advantage of the opportunities provided by ICTs (Kleine, 2013; Walsham, 2017). For instance, gender-based inequalities in access to and use of ICTs can limit female farmers' sense of choice and agency in adopting new technologies or practices (Wyche & Steinfield, 2016). Therefore, we also provide an analysis of the context in which ICTs perform well, based on published studies. For example, to improve the choice aspect, Mushi et al. (2023) proposed a framework in Tanzania that integrates different modules (farmers' data, agro-dealers, farm inputs, advisory, and market data) to provide comprehensive support to smallholder farmers and ease their selection of alternatives.

The use of choice refers to the adoption of agricultural practices as a result of ICTs. This dimension is crucial for understanding the effectiveness of ICT-based extension in driving development outcomes such as increased productivity, income, and well-being (Aker et al., 2016; Deichmann et al., 2016) through the adoption of practices promoted through ICTs. The Choice Framework emphasizes the importance of considering both the quantity and quality of choice, as well as the sustainability and autonomy of choice use over time (Kleine, 2013).

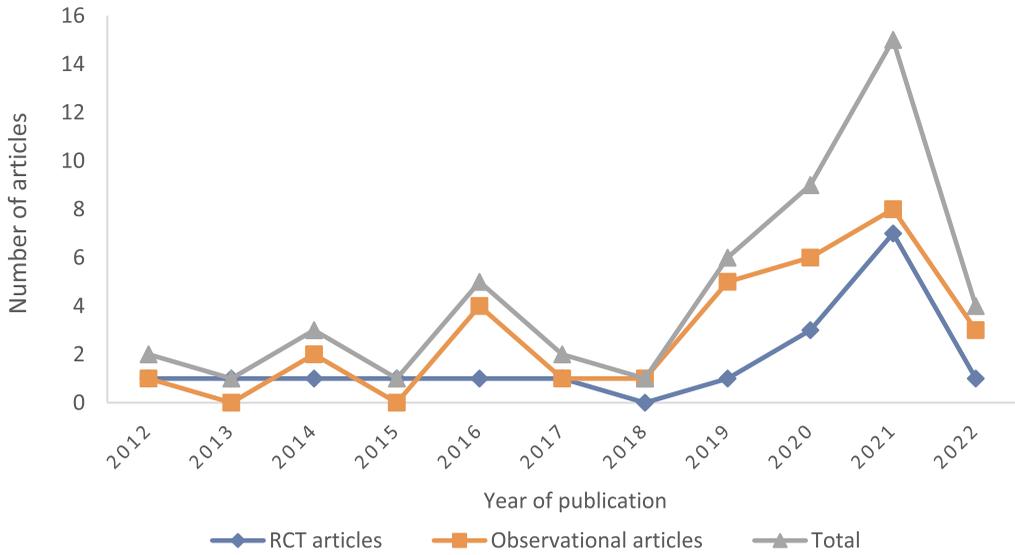
Finally, the achievement of choice relates to the realization of desired outcomes and the expansion of capabilities as a result of using ICT-enabled services. In the case of smallholder farmers, this could manifest in improved livelihoods, productivity, and income (Aker et al., 2016; Nakasone et al., 2014). However, the achievement of choice is not automatic and may be influenced by various conversion factors, such as institutional arrangements, social norms, and individual characteristics (Kleine, 2013).

Kleine's Choice Framework provides a valuable lens through which to analyze the impact of ICT-based extension services on smallholder farmers. The four dimensions of choice – existence, sense, use, and achievement – align closely with the outcomes examined in this review. Awareness of agricultural technologies relates to the 'existence of choice' as ICTs can expand farmers' knowledge of available options. Adoption of these technologies represents the 'use of choice', while improvements in yield and income can be seen as 'achievement of choice'. This framework guides our analysis of how ICT interventions contribute to expanding farmers' capabilities and choices in agricultural decision-making.

### 3. Results

#### 3.1. Studies characteristics

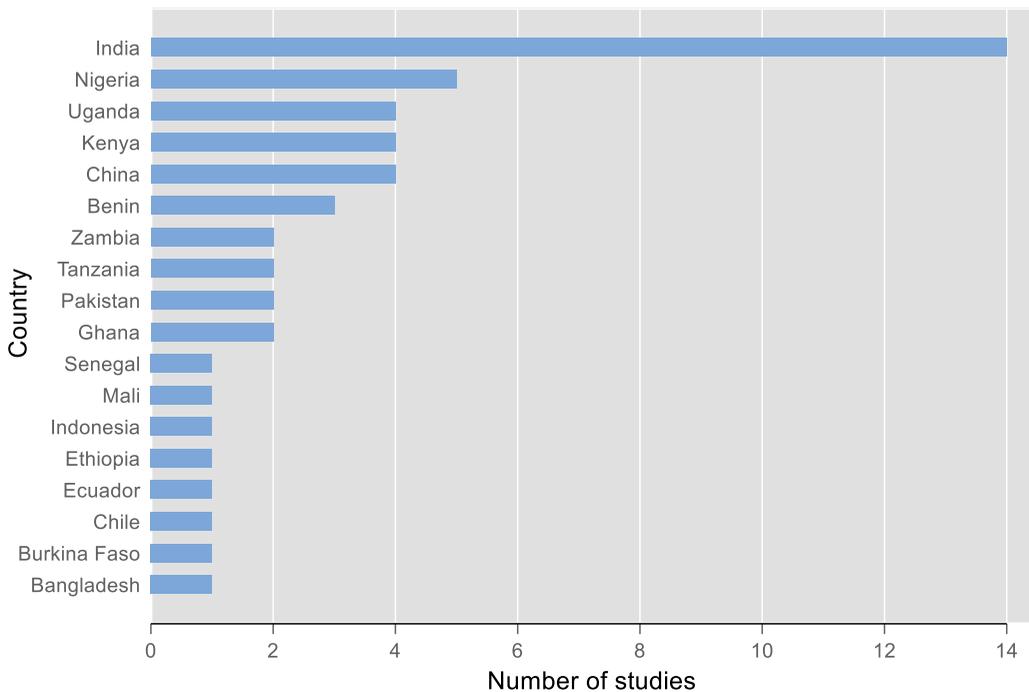
In total, we identified 49 relevant studies, mostly observational studies ( $n = 26$ ) and randomized control trials ( $n = 23$ ). The outcomes of interest identified from these studies were the impact of



**Figure 2.** Number of observational and RCT articles published by year.

ICT on awareness, adoption, yield, and income. The studies were published between 2012 and 2022. Most papers were published in 2021 ( $n = 15$ ) and 2020 ( $n = 9$ ). See [Figure 2](#).

[Figure 3](#) shows the countries in which the studies were conducted. Most studies on the impact of ICTs are conducted in Africa (26), Asia (21), and South America ( $n = 2$ ). The countries with most studies were India ( $n = 14$ ), followed by Nigeria ( $n = 5$ ) then Kenya ( $n = 4$ ), Uganda ( $n = 4$ ),



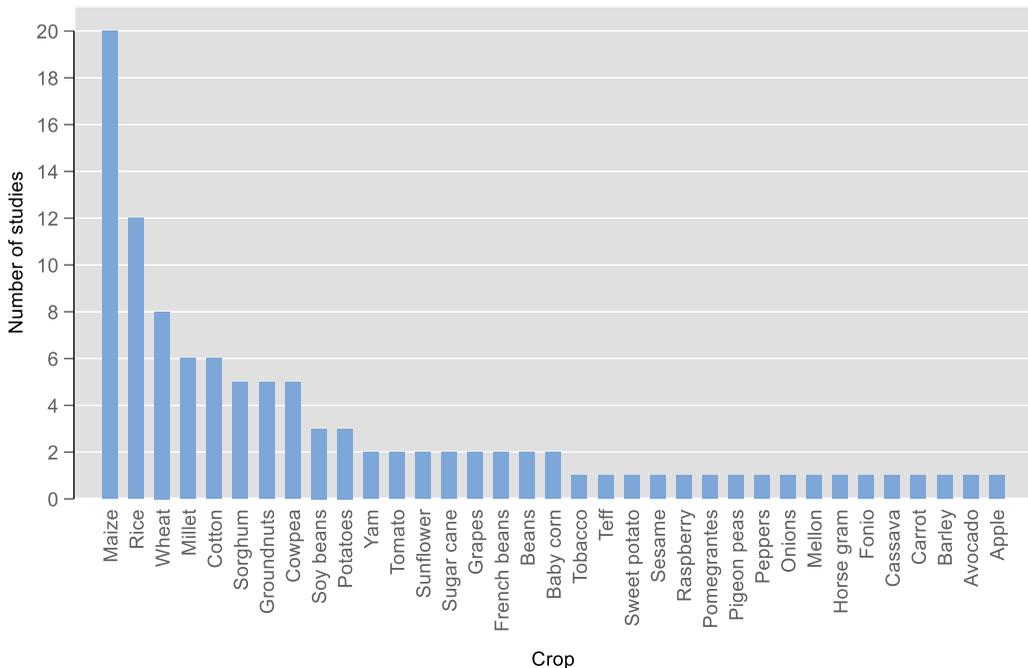
**Figure 3.** Number of studies included in the review per country.

China ( $n = 4$ ), Benin with ( $n = 3$ ), Ghana ( $n = 2$ ), Tanzania ( $n = 2$ ), Pakistan ( $n = 2$ ) and Zambia ( $n = 2$ ), the rest of the countries each had one study: Bangladesh, Chile, Indonesia, Mali, Burkina Faso, Ethiopia, Ecuador, and Senegal.

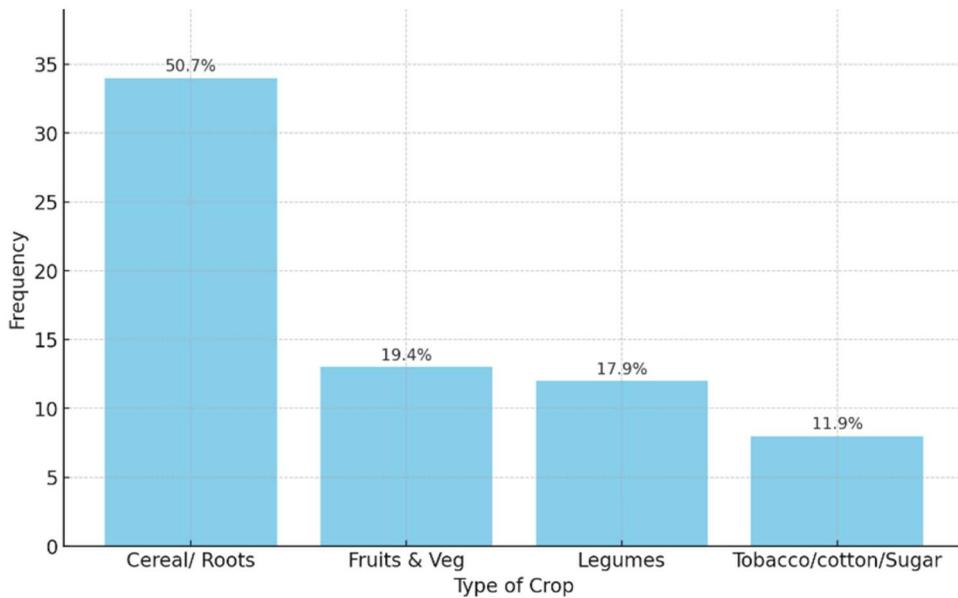
### 3.2. Agricultural technologies promoted through ICTs and types of ICTs used

Our review focuses mainly on crop agriculture in developing countries. Our criteria excluded any study that did not focus on crop farming. If a study focused on more than one crop, it was included in any crop it looked at. Several studies have used multiple crops. In total, we recorded 34 different crop types (Figure 4). At the crop level, maize is by far the most studied crop, especially in Africa. Twenty studies focused on maize. We then categorized the crops into different types, as shown in Figure 5. The most common crop type in these studies was cereal/grain (e.g. maize, rice, wheat, millet, sorghum); at least 34 studies reported on cereals. Legume crops (cowpeas, pigeon peas, beans, French beans, etc.) were reported in 10 studies. Cash crops such as cotton were recorded in seven studies. Other crop types, such as vegetables, were recorded in two studies, and root vegetables (e.g. yam, sweet potato, cassava) were reported in five studies. Fruits were recorded in four studies. Only one study reported on sugarcane. See Figure 5 for the different classifications of crops presented in the study. While these patterns follow similar patterns in terms of extension and policy with a focus on maize and cereals, there is a missed opportunity to promote diversification through ICTs, which can be tailored to minor but nutritionally important crops at a lower cost.

Table 1 shows the most common types of ICTs used for agricultural information dissemination. Mobile apps are one of the most commonly studied tools and consistently demonstrate impacts on adoption, yields, and incomes (Aker et al., 2016; Benin, 2017; Mittal et al., 2012). Their versatility in providing personalized, hyperlocal, and interactive content seems to be the key to their success. Apps enabled customized guidance on practices, such as site-specific nutrient management, that have led to productivity gains (Arouna et al., 2021; Oyinbo et al., 2022). Their multimedia features



**Figure 4.** Focus crops from the ICT-based information dissemination studies. If one study focused on more than one crop, it is counted across all crops it focuses on.



**Figure 5.** Types of crops on which ICT studies focus and their percentage distribution.

improve knowledge retention and support behavior change better than basic SMS or radio (Fabregas et al., 2019). However, smartphones and digital literacy remain barriers to the reach of apps for many smallholders (Baumüller, 2018). Further research is needed on participatory app design and bundling with training.

SMS is one of the most widely studied tools, and frequently increases adoption and yields when implemented thoughtfully (Fabregas et al., 2019). SMS is nearly universally accessible on basic mobile phones, enabling broad reach across contexts. Timely messages can influence decision making by delivering information when it is most relevant (Cole & Fernando, 2021). However, SMS has limitations for complex topics that require nuanced guidance. Some studies, such as Lasdun et al. (2022), found SMS insufficient to change practices compared to more interactive app platforms. SMS success depends on message timing, frequency, design, and pairing with training.

Video interventions frequently increase farmers' knowledge, adoption intention, and self-efficacy by visually demonstrating practices (Van Campenhout et al., 2021; Vasilaky et al., 2015). Videos can convey complex information more clearly and improve retention compared with text or audio-only formats. However, passive video viewing alone may be insufficient; facilitation and embedding

**Table 1.** Types of ICTs used in the reviewed studies.

Type of ICT	Frequency	Percent
App	11	18.97
Phone ownership	9	15.52
SMS	9	15.52
Video	7	12.07
Voice calls	7	12.07
General	6	10.34
Radio	3	5.17
SMS & Voice calls	3	5.17
Computer	1	1.72
SMS, Radio & Videos	1	1.72
Video & Radio	1	1.72
Total	58	100

Notes: Some studies used more than one type of treatment.

videos within interactive platforms are important for sustained impacts (Cole & Fernando, 2021). Access to smartphones is limited in some areas. Overall, thoughtfully designed and facilitated videos show high potential for remote learning.

Basic voice call services and phone ownership have enabled advisories and coordination, with largely positive outcomes (Camacho & Conover, 2011; Dzanku et al., 2021). Calls facilitate personalized guidance and relationship building between experts and farmers. However, the content quality transmitted through calls is crucial – phone access alone sometimes lacked impacts compared to more robust ICT interventions (Aker et al., 2016). User digital skills also mediate success. Voice-based tools remain relevant but may need bundling with other support.

A few studies examined radio and TV, finding them effective for raising awareness, but less suitable for complex behavioral changes like agricultural practices adoption (Tambo et al., 2019; Van Campenhout et al., 2021). Passive radio and TV are limited by one-way information flow. However, interactive radio programs have successfully disseminated agricultural information through local languages, storytelling, and drama (McCullough, 2014). Overall, radio/TV is still relevant but may need pairing with more targeted tools.

The ICT type categorized as general focused on access to any type of ICT, in some cases, a combination of phone, TV, computers, and radio (Das et al., 2017). Some studies combined the use of different types, for example, using videos, radio, and sending SMS reminders, as one treatment (Tambo et al., 2019). The last most common form of ICT identified and assessed in the reviewed studies was the use or ownership of computers (Hou et al., 2018). This study assessed how households with access to a computer performed in terms of adoption of technology and production outcomes.

While no ICT universally outperforms it, mobile solutions hold particular promise owing to their accessibility, personalization, and interactivity. However, supportive policies, training, and participatory design remain essential to maximize their benefits. Further research on emerging digital innovations can guide ICT interventions to meet smallholder needs effectively.

Table 2 summarizes the most common agricultural technologies promoted through ICTs. Agricultural technologies promoted through ICTs varied vastly and were mainly related to agronomic practices. We categorized practices into nutrient management if they were about fertilizer application (inorganic or organic), inoculation, or technical information about returns to fertilizer, soil fertility, and others. The sustainable agricultural practices category includes any of the practices that are aimed at using resources sustainably, such as conservation agriculture, intercropping, and minimum tillage. Other practices were categorized as ‘crop management.’ These include practices such as spacing, early planting, weeding after the recommended number of days from planting, and row planting. We also included a category to capture pest and weed management, which had a few studies sending messages on pesticide toxicity, implementing integrated pest management, and use of pesticides. Other categories are ICTs that provide weather and climate information, marketing, and improved seeds or different seed choices, such as those promoting drought-tolerant varieties. We have provided examples of the studies and the specific technologies in the last column for guidance.

Studies on nutrient management were the majority (approximately 28%). These studies overwhelmingly focused on providing fertilizer recommendations, including type, timing, dosage, and site-specific guidance (Arouna et al., 2021; Li et al., 2022; Oyinbo et al., 2022). The messages were delivered via mobile apps, SMS, videos, and voice calls. Most found positive impacts on adoption, yields, and sustainability outcomes. Personalized, localized recommendations enable precise nutrient application, thereby avoiding waste and environmental damage (Aker et al., 2016). However, some SMS and radio messages lacked impact, likely because basic formats struggle to convey nuanced soil fertility advice (Fabregas et al., 2019). Overall, tailored nutrient management messaging shows a high potential, but its success depends on message relevance and platform interactivity.

Studies promoted various sustainable approaches, such as conservation agriculture, climate-smart techniques, and integrated pest-crop management (Chua et al., 2021; Zheng & Ma, 2023). SMS, smartphones, and videos provided information with largely positive effects on productivity and environmental outcomes. For example, an app can reduce fertilizer overuse (Naik & Krishna, 2021).

**Table 2.** Types of agricultural practices/ technologies promoted through ICTs.

Technology	Freq.	Percent	Examples of specific technologies
Nutrient Management	18	27.27	Aminou et al. (2018) – Fertilizer recommendations for maize Arouna et al. (2021) – Fertilizer recommendations for rice Campenhout (2021) – Fertilizer practices for rice Casaburi et al. (2014) – Fertilizer delivery and use for sugarcane Cole et al. (2020) – Fertilizer use recommendations Dzanku et al. (2022) – Inoculants for legumes Fabregas et al. (2019) – Lime use recommendations
Sustainable Agricultural Practices	10	15.15	Das et al. – Sustainable intensification practices for rice, wheat, maize Djido et al. (2021) – Climate-smart practices for various crops Lasdun et al. (2022) – Soil conservation for maize Naik and Krishna (2021) – Organic fertilizers for rice and cotton Olayemi et al. (2021) – Good agricultural practices for various crops
Crop Management	9	13.64	Campenhout (2021) – Cultivation practices for rice Chua et al. (2021) – Cultivation techniques for grapes Das et al. – Practices for rice, wheat, maize and pulses Dzanku et al. (2021) – Grain storage technologies Fafchamps and Minten (2012) – Changed crop varieties and practices for various crops
Improved Seeds	7	10.61	Dzanku et al. (2022) – Improved legume seeds Gupta et al. (2020) – High yielding varieties seeds for rice and wheat Kiiza and Pederson (2012) – Improved seeds for various crops Mittal and Tripathi (2009) – Improved vegetable seeds Nikam et al. (2022) – Improved cotton seeds Rengaraj and Shibu (2020) – Seeds and fertilizers for maize Voss et al. (2021) – Certified seeds for rainfed crops
Weather And Climate Information	6	9.09	Fafchamps and Minten (2012) – Weather forecasts for various crops Sharma et al. (2021) – Agro-met advisories for wheat Umadikar et al. (2014) – Weather information for paddy Yegbemey et al. (2021) – Weather forecasts for maize
Integrated Pest Management	3	4.55	Chua et al. (2021) – Pest management for grapes Djido et al. (2021) – Pest management practices for various crops Larochelle et al. (2019) – IPM techniques for potato Mittal and Tripathi (2009) – Pesticides for beans and corn Subramanian (2021) – Pest management for pulses Tambo et al. (2019) – Fall armyworm management for maize
Market And Price Information	3	4.55	Asad (2015) – Market and pricing data for various crops Fafchamps and Minten (2012) – Crop prices for various crops Haile et al. (2019) – Market price data for grains Khan et al. (2022) – Marketing data for wheat Okello et al. – Market data for various crops
Post-Harvest	3	4.55	Asad (2015) – Post-harvest management for various crops Dzanku et al. (2021) – Grain storage technologies Maredia et al. (2018) – Post-harvest technologies for cowpea
Crop Diversification	2	3.03	Aker and Ksoll (2016) – Crop diversification for various crops Asad (2015) – Growing of fruits and vegetables
Labour Management	2	3.03	Fu and Akter (2016) – Labor practices at the household Hou et al. (2018) – Computer and internet to reduce labor for apple Mittal and Tripathi (2009) – Hired labor use for beans and corn
Pest Management	2	3.03	Mittal and Tripathi (2009) – Pesticides for beans and corn Subramanian (2021) – Pest management for pulses
Water Management	1	1.52	Chua et al. (2021) – Water management for grapes
Total	66	100	

Note: The examples of studies are not exhaustive and are selected only to show some specific technologies promoted under each broad category used in this study.

By connecting farmers to global sustainable farming knowledge, ICTs enabled the adoption of eco-friendly local practices (Tambo et al., 2019). However, changing complex agronomic decision-making requires comprehensive training alongside technology access (Baumüller, 2018).

Key crop management messages focus on planting and the timing of some cultural practice recommendations (Dzanku et al., 2021; Sharma et al., 2021). Voice calls, SMS, and video interventions

facilitated timely information delivery, leading to yield gains in many cases. However, basic SMS struggled to alter some crop practices compared to apps (Lasdun et al., 2022). Overall, ICTs show potential for improving cultivation techniques when paired with training and two-way exchanges to build skills (Cole & Fernando, 2021) and SMS reminders for performing given tasks for crop management.

Studies have promoted certified high-quality seeds of various crops via SMS, radio, and video (Dzanku et al., 2022; Voss et al., 2021). Adoption increased substantially in most cases, subsequently raising yields per evidence. ICTs have enabled cost-effective awareness and availability of improved varieties. However, realizing yield gains also depends on access to complementary inputs. Therefore, targeted seed promotion through ICTs should integrate input access and training.

Weather and climate information contained weather forecasts, disaster warnings, and climate-smart advisories, delivered by SMS, radio, and calls (Yegbemey, Aloukoutou, et al., 2021). Evidence on yield impacts is mixed, as weather information alone cannot alter agronomic practices (Fafchamps & Minten, 2012). However, some studies found positive income effects from avoided losses (Umadikar et al., 2014). To leverage ICT-enabled climate services, capacity building for decision-making and climate-smart techniques are essential complements.

Integrated Pest Management (IPM) studies have focused on increasing IPM knowledge and adoption through SMS, videos, and hotlines (Chua et al., 2021; Tambo et al., 2019). Most studies have shown significant pest control and yield improvements by enhancing timely practices, such as scouting and pesticide application. However, basic SMS struggled to convey comprehensive IPM (Larochelle et al., 2019). Overall, ICTs are well-suited to disseminate pest control information, but multimedia formats may perform better than text-only messages.

Market and price information mostly focuses on income outcomes. Simple price data provision via phones increased incomes by informing marketing timing and relationships with traders or buyers (Asad, 2015; Okello et al., 2020). However, more complex arbitrage or grading behavior change had a limited impact from basic SMS (Fafchamps & Minten, 2012). Price information is necessary, but insufficient capacity building in financial literacy and post-harvest handling enables farmers to capitalize on market access.

Post-harvest advisories on drying, storage, and processing techniques have helped reduce losses and quality degradation (Dzanku et al., 2021; Maredia et al., 2018). Voice calls, videos, and interactive voice systems enabled clear demonstrations and guidance. Adoption was generally high, particularly for simpler technologies such as improved storage. However, environmental and resource constraints also affect post-harvest success, warranting integrated solutions.

Overall, ICTs demonstrate substantial potential for delivering tailored agricultural messaging to remote farmers. However, support through training, access to complementary inputs and markets, and needs-based design is essential to translate information into impact. A comprehensive approach that harnesses the strengths of different platforms can drive widespread progress.

### ***3.3. Impact of ICT-based extension on agricultural outcomes***

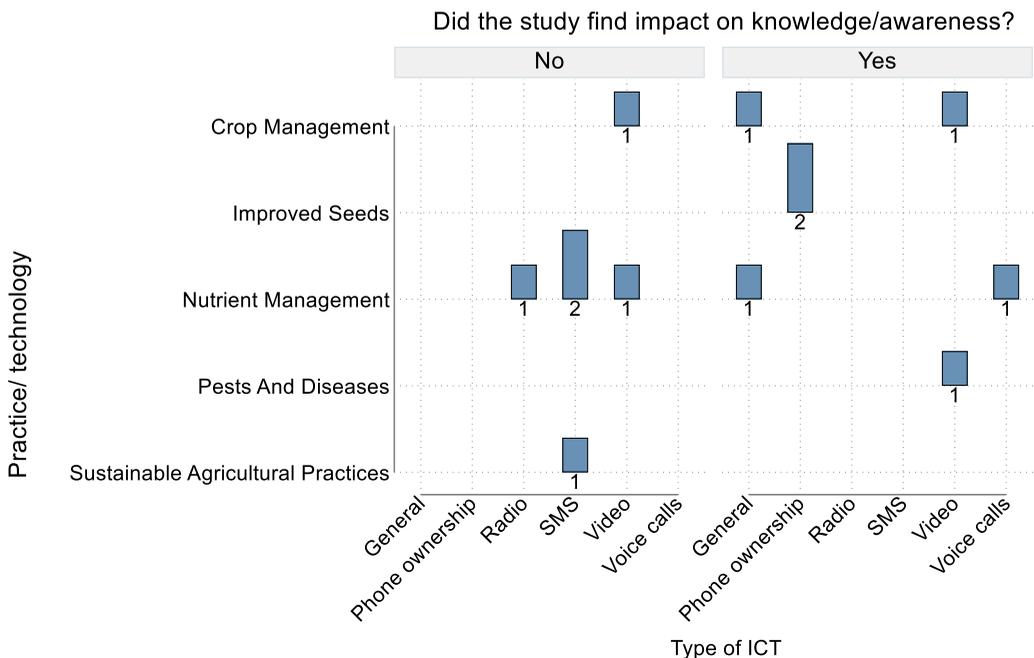
Many studies in our review evaluated the impact of ICT on agricultural productivity. Studies reporting on the impact of ICTs on awareness used scores from a set of exam-like questions or a binary variable (1 for a correct answer, zero otherwise), while others simply asked if a farmer is aware of a certain technology. Adoption was measured most uniformly as a binary variable if a farmer adopted a particular technology. The standard unit of measurement for most articles reporting on the impact on yield was an increase in yield by percentage points due to ICT-delivered information. However, the dependent variables were not uniform. Some studies used the log of output in kilograms per acre, while others used the actual kgs/acre. Because many studies used different methodologies, but all of them had one aim, we had to find a standard way to measure the impact. For this reason, our systematic analysis looks at the binary interpretation of the findings (yes if the study found a significant positive impact, and no otherwise). For studies with multiple technologies and estimations, we use a simple majority rule counting the number of regressions where there is a

significant positive coefficient and categorize any study/treatment with >50% of the regressions with a positive impact as having a positive impact. For example, a regression on radio listening club impact with three different regressions in which two show a positive impact is categorized as having an impact. For some studies that used different ICT types or agricultural technologies, we separated the impact by ICT type (if it is different) or by agricultural technology type. Hence, we summarize our findings, explaining the proportion of studies or treatments that report an impact or none for each outcome.

**3.3.1. Impact on knowledge/awareness**

We found 10 studies that reported an impact on awareness or knowledge of the technology being promoted through ICT. These studies are summarized in Figure 6 by the technology promoted, ICT type used, and whether they found a significant positive impact (Table A1 reports the details of each study). ICT interventions included videos, voice calls, SMS messages, radio programs, and basic mobile phone ownership. Agricultural practices covered topics such as crop management (a general category for practices such as optimal weeding time, time to apply fertilizer, and others), use of improved seeds (hybrids), nutrient management (e.g. fertilizer use, inoculant technology), pest and disease management and identification, and sustainable agricultural practices. Sustainable agricultural practices aim to make farmers more resilient to climate change and sustainable farming. These include crop rotation, drought tolerant varieties, mulching, etc. Overall, the results were mixed: six studies/treatments found no impact on the knowledge of the given technologies, while seven found a positive impact on the knowledge of certain technologies.

Some patterns emerge in terms of which interventions were more successful and which were less successful. Studies that consider general ICTs (i.e. access to any form of ICT) find that farmers with access to ICTs have a higher knowledge of nutrient management and crop management. The only RCT (Dzanku et al., 2022) that considered the impact of radio listening clubs on inoculant technology knowledge found that knowledge about the technology did not change compared with the



**Figure 6.** Studies reporting the impact on knowledge/awareness.

control. All three studies that used SMS based extension did not find any impact, irrespective of the technology being promoted or the type of study (RCT or observational). Video-based extension led to gains in awareness in two out of four studies. The visual demonstration of practices may support farmers in learning more than text or audio-only formats. However, passive video presentation alone may be insufficient. Van Campenhout et al. (2021) found limited impacts, likely because the content was not new information.

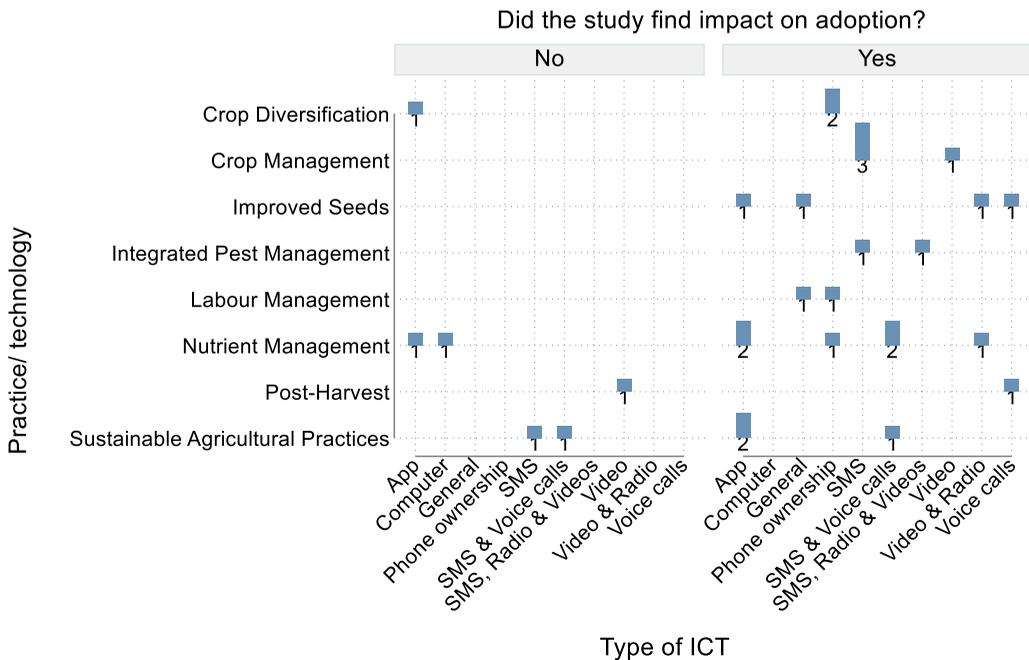
No single ICT format universally increases knowledge across contexts and practices. This highlights the need for technology choice and program design to consider local conditions, needs, and capabilities. Passive information delivery alone appears insufficient – facilitating active learning and two-way exchange is likely key to amplifying ICT impacts on awareness.

The y-axis shows the technologies that were promoted through ICT, and farmers were evaluated for their knowledge about them. The x-axis shows the types of ICTs used to provide information about the technologies. The figure shows the number of studies using a given ICT type to provide information about a given technology by whether they found an impact.

### 3.3.2. Impact on adoption

Figure 7 provides useful insights into the potential of different ICT tools to drive the adoption of agricultural technologies (more details in Table A2 in the appendix). SMS emerges as one of the most consistently effective formats – it increased adoption in eight out of ten studies that had a component of SMS. This is likely because SMS is highly accessible to farmers via basic mobile phones, can deliver timely reminders and advisories, and enables two-way communication. Technologies successfully promoted through SMS include integrated pest management, good agricultural practices, fertilizer use, and marketing timing.

However, SMS had mixed results in a few cases. For complex topics such as erosion control (sustainable agricultural practices), basic SMS may lack the depth to change behaviors (Djido et al., 2021).



**Figure 7.** Impact of ICT-based extension on adoption of different practices/technologies. The graph shows the number of studies showing no impact or positive impact (yes) by the type of practice promoted and the type of ICT used. The length of the bars indicates number of studies which is also displayed below each bar.

Timing and literacy can also influence SMS success; for example, Lasdun et al. (2022) found a limited impact, potentially because messages were not well-matched to farmer needs. However, most evidence points to SMS as a promising ICT option for increasing adoption. Smartphone apps also drove adoption in five out of seven studies. Their interactive, multimedia, and hyperlocal capabilities allow personalized guidance. Apps have improved the adoption of practices such as formula fertilization (nutrient management) (Li et al., 2022), pest management (Naik & Krishna, 2021), and soil testing (nutrient management) (Chua et al., 2021). However, apps require smartphones and stronger digital skills.

Video extension was uniformly effective, increasing the adoption of technologies such as seed inoculants and rice intensification (Dzanku et al., 2022; Vasilaky et al., 2015). Video's visual nature can clearly demonstrate new practices and boost farmers' self-efficacy. However, television and computer reach remain limited in some areas. Voice calls promoted adoption across crops, fertilizer use, and storage technologies in five out of six studies. Personal interaction enables trust-building and nuanced guidance. However, basic mobile ownership lacks impact in some cases (Cole et al., 2020), highlighting that call centers must actively disseminate relevant information. Radio worked well for raising awareness (Tambo et al., 2019). However, passive radio content sometimes insufficiently changed behaviors such as seed choice (Dzanku et al., 2022). Creative radio programs with storytelling appear to be the most impactful. Notably, several RCTs have provided strong evidence of the causal impact of ICTs on technology adoption. For instance, Arouna et al.'s (2021) RCT in Nigeria found that personalized digital extension advice significantly increased the adoption of recommended rice farming practices. Similarly, Cole and Fernando's (2021) RCT in India demonstrated that mobile phone-based agricultural advice increased the adoption of more profitable input combinations.

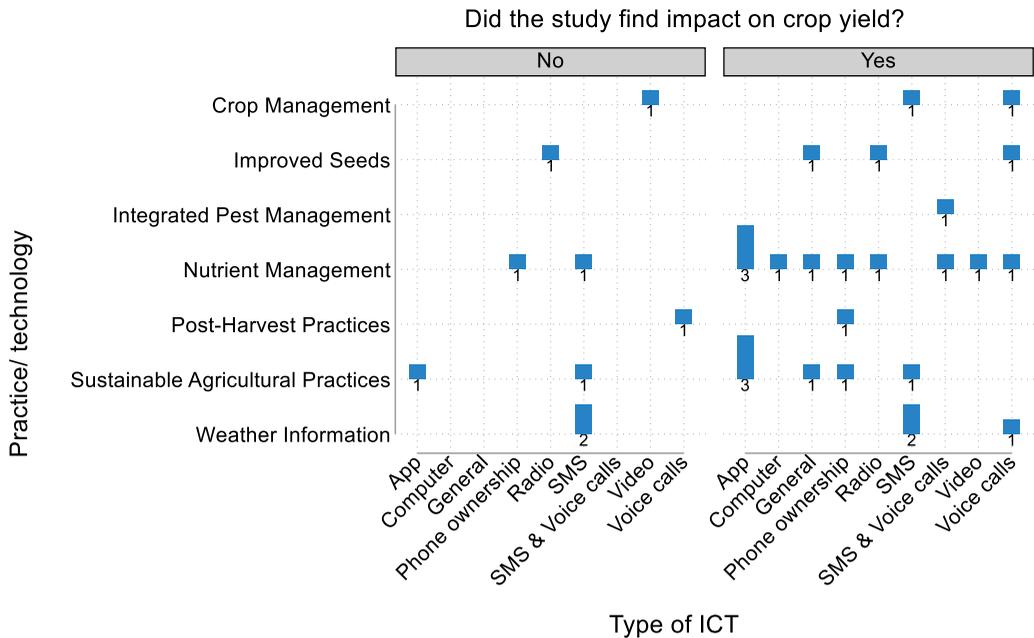
From this, the benefits of ICTs are clearest for straightforward agronomic topics, such as fertilizer application (nutrient management), planting practices (crop management), pest management, and post-harvest handling. Capital-intensive technologies, such as new seed varieties, remain challenging to promote. Multimedia formats and two-way advisory services generally outperform basic text messages and phone ownership alone. However, SMS can still be impactful when well designed and targeted. Thoughtful implementation and bundling ICT with other interventions, such as training and access to inputs, enhances success.

### 3.3.3. *Impact on yield*

Figure 8 summarizes 32 studies examining the impact of various ICT tools on crop yields. The studies (some broken into two if they focused on a different ICT tool for each treatment) were broken down by technology being promoted and the ICT tool used (further details are provided in Table A3 in the appendix). We find that 72% of the studies (23 out of 32) found that ICT-based extension increased yields for farmers. The most common technologies that positively impacted yields were smartphone apps, SMS, voice calls, and videos. Only one study found that an app did not increase yields compared to six studies that found a positive impact on yield. App versatility and personalization appear to be highly valuable for yield gains.

All studies that consider general access to ICTs find that those with access have higher yields. These studies could be compromised by endogeneity issues. However, basic mobile phone ownership and radio/TV showed mixed results; they increased yields in some cases but lacked impact in other studies. This highlights that just having access to a phone or radio is insufficient – farmers need relevant, timely information and training on using ICTs.

The technologies most commonly promoted through successful ICT interventions were improved nutrient management (with fertilizer being the most common) and sustainable agricultural practices such as the use of organic fertilizer and crop rotation. More complex technologies, such as introducing new varieties and technologies (e.g. inoculants), sometimes lack yield impacts (Dzanku et al., 2022; Fafchamps & Minten, 2012). Effective promotion of new innovations requires formats with more detailed guidance, such as apps and videos. SMS messaging, alone and when combined with voice calls, increased yields in six out of eight studies. When timed appropriately for key



**Figure 8.** Impact of ICT-based extension on yield.

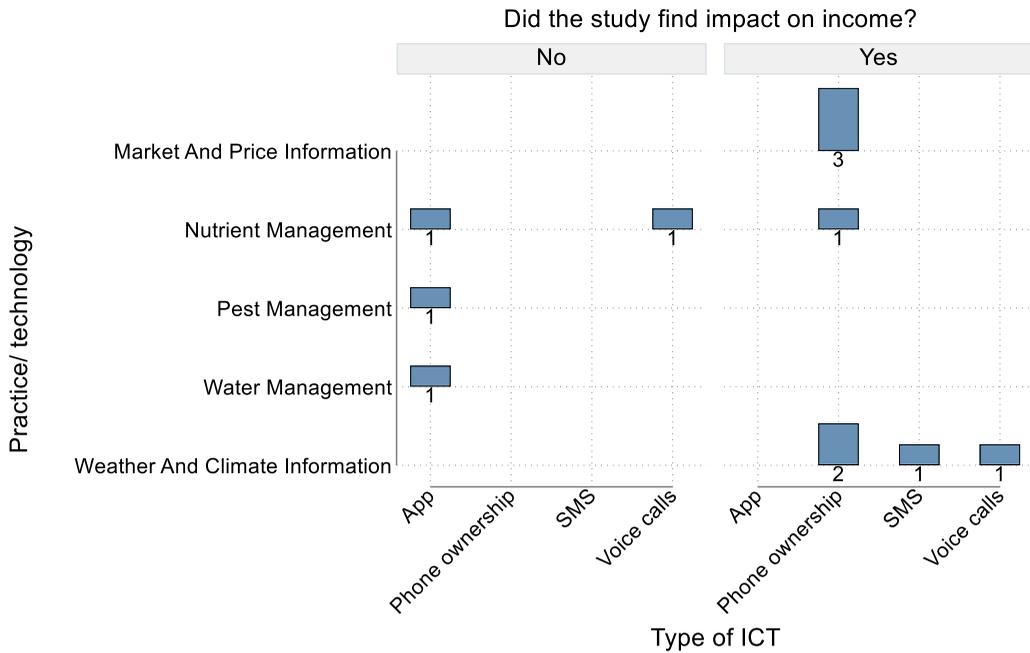
decisions, SMS can provide effective advice to boost productivity. However, some studies found limitations of basic SMS compared to apps (Lasdun et al., 2022). Voice calls were successful across multiple crops and interventions, leveraging personalized advice. However, basic call centers without strong technical content had less impact (Sharma et al., 2021).

When comparing RCTs to observational studies on the impact of ICTs on crop yields, we found that both types of studies generally show positive effects, but RCTs provide more nuanced and causally robust results. Of the 32 studies examining yield impacts, 15 were RCTs. Although 72% of all studies found positive yield impacts, RCTs tended to report modest and context-specific effects. For instance, an RCT by Arouna et al. (2021) found that personalized digital extension advice increased rice yields by 8.9% in Nigeria, a significant but measured improvement. In contrast, some observational studies have reported larger yield increases, such as Das et al., who found that ICT use was associated with 20-25% higher yields for various crops in Bangladesh. This difference suggests that observational studies may overestimate yield impacts owing to confounding factors. However, RCTs also revealed important nuances, such as Fabregas et al. (2019) finding that SMS-based interventions had varying effects depending on message content and timing. These RCT findings provide stronger evidence for causal relationships between specific ICT interventions and yield outcomes, offering more actionable insights for policy and practice.

These results emphasize that ICT format, content, implementation quality and complementary support all influence impact on productivity. While no digital tool universally increases yields in all situations, multimedia interventions such as videos and apps tailored to local contexts show particular promise and warrant further study.

### 3.3.4. Impact of ICT-based extension on income

Figure 9 summarizes the studies that examined the impact of ICT tools on farmer incomes (details of the studies and the findings are in Table A4 in the appendix). We found nine studies and a total of 12 different treatments. Overall, eight out of 12 studies/treatments (78%) found that ICT interventions increased income, while four studies showed no significant impact. In terms of ICT formats, smartphone apps results were mixed – three studies showed no income gains from apps. For example,



**Figure 9.** Impact of ICT-based extension on income.

providing agronomic and water management, pest management, or nutrient management advice (Chua et al., 2021) did not increase income. This highlights that standalone apps may be insufficient without field training or facilitation.

Most studies on income focus on phone ownership, with the understanding that phones can be used in several ways to increase farmers' income. Basic mobile phone ownership and access to voice call services increased income in all six studies. Phones and call centers enable farmers to access valuable market price information and climate advisories to reduce costs and losses (Aminou et al., 2018; Asad, 2015). However, voice calls promoting improved inputs lacked income impacts in one case (Rengaraj & Shibu, 2020), highlighting that complementary interventions are still needed to overcome barriers to the use of improved inputs. SMS messaging improved incomes in the study reviewed by providing timely weather information to guide farm decisions (Yegbemey, Bensch, et al., 2021). However, SMS has limitations in terms of complex topics.

In terms of the agricultural technologies promoted, market information services, climate advisories, and improved agronomic practices were most commonly linked to income gains. However, an app improving production techniques did not increase incomes (Chua et al., 2021), underscoring the need for interventions to connect farmers to markets. The two studies reporting no income impacts pointed to factors such as missing credit access and poor targeting of video content as reasons for lack of success. This emphasizes the need to bundle ICTs with other services to enable farmers to implement new practices.

The comparison between RCTs and observational studies for income outcomes revealed a similar pattern, albeit with a smaller sample size. While 50% of the RCTs (one out of two) reported positive impacts on income, 85.7% of the observational studies (six out of seven) showed positive effects. Importantly, RCTs were more likely to report null or mixed income effects, such as Fafchamps and Minten (2012), who found no significant impact of SMS-based price information on farm gate prices or profits. These results highlight the complexity of translating ICT-driven knowledge and practice changes into income gains, emphasizing the need for comprehensive approaches that address the multiple constraints facing smallholder farmers.

ICTs can effectively raise farmers' incomes through market linkages, climate information services, and improved production techniques. However, the outcomes depend on user training, facilitation, and access to complementary services. A comprehensive approach is required to realize the full benefits of ICTs on income.

## 4. Discussion

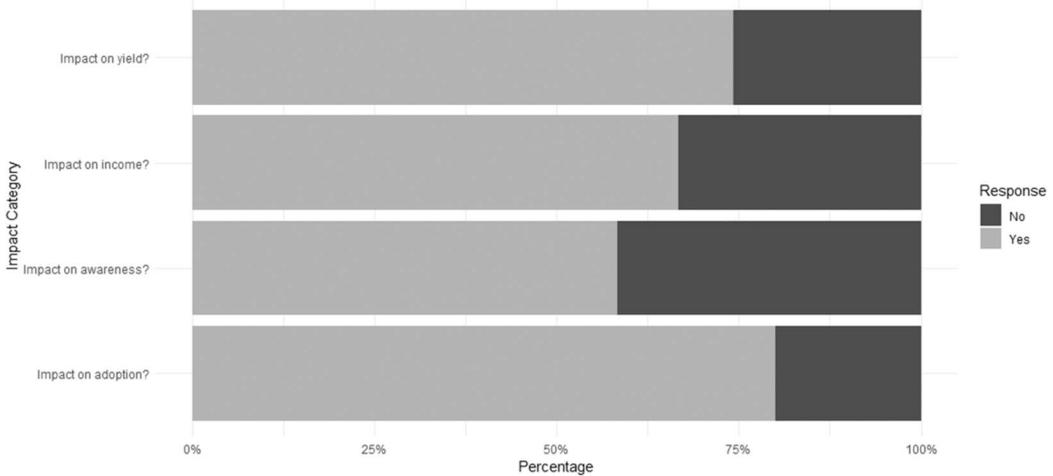
The implementation of ICT in agricultural extension services stems from the need to address the information needs of underprivileged smallholder farmers in developing nations. It is evident that more efficient extension services are required, and many organizations and specialists in the field of agricultural extension are encouraging agricultural extension and education agents to employ ICTs (Tata & McNamara, 2016). ICTs can speed up the transfer of agricultural technologies from laboratories to farmers (Tata & McNamara, 2016). ICTs are rapidly expanding in rural areas of developing countries, opening up new potential to support the coordination of agricultural agents and give farmers more prompt and affordable information services (Aker et al., 2016). This study aimed to determine the effect of ICT-based extension services on smallholder farmers in Sub-Saharan Africa by reviewing studies that estimated the effect of ICTs on four outcomes: awareness, adoption, crop yield, and income. We also reviewed the most common types of ICTs, crop studies, and types of technologies promoted through ICTs.

Our findings contribute to the growing body of literature on ICTs and development (Heeks, 2002; Walsham, 2017). By systematically reviewing the evidence on the impact of ICT-based extension on smallholder outcomes, we provide insights into how digital technologies can foster economic and social development in agricultural contexts. The positive impacts on awareness, adoption, yields, and income align with arguments that ICTs can empower marginalized communities and enhance livelihoods (Kleine, 2013; Unwin, 2009). However, the mixed results and challenges highlight the importance of considering contextual factors, complementary interventions, and participatory approaches in ICT4D initiatives.

Overall, we found that there has been an increase in the number of studies since 2010 that investigate the role of ICTs in agriculture with a focus on information delivery. In recent years, the share of studies conducted through randomized controlled trials has increased, which means there is more robust evidence of the impact of ICTs (Escobal & Ponce, 2020). The most common types of ICTs for digital advisory services are apps, and voice calls and nutrient management technologies (fertilizer mostly and inoculants) are the most common type of technology promoted through ICTs. The most common crops are cereals, with maize as the number one and rice as the number two.

### 4.1. Impact by outcome – what works and does not work?

When we focused on the summary of the proportion of studies that found a positive impact by outcome (Figure 10), we found interesting results. The review found mixed impacts of ICT interventions on farmers' agricultural knowledge and awareness. About 60% of the studies showed that ICT-based extension increased knowledge. Conversely, despite the touted effect of ICTs on bridging the knowledge gap, as farmers can access information readily, about 40% of the studies find no positive impact of ICTs on knowledge. There seems to be no systematic pattern of the type of ICTs and impact; for example, some video-delivered extension in the same country (Uganda) find a positive impact (Van Campenhout et al., 2021) but no impact in another study (Campenhout, 2021). Furthermore, there does not seem to be systematic differences across technologies being promoted, for example, while both studies evaluated awareness of knowledge about an inoculant technology, Dzanku et al. (2022) mainly found no effect of video-delivered information or radio listening club on knowledge, while Mohammed and Abdulai (2022) found a significant effect on knowledge. However, some patterns can be observed across countries. For example, Van Campenhout et al. (2021) found SMS to be ineffective in conveying nuanced practices compared to demonstration



**Figure 10.** Proportion of studies/treatments that have a significant impact by outcome.

videos. However, Fabregas et al. (2019) note that SMS can raise awareness if content is simple and locally relevant. Overall, the findings suggest that ICTs have the potential to augment knowledge if designed appropriately for user literacy and decision needs. Realizing this impact may require bundling ICT with participatory training approaches (Baumüller, 2018).

More studies show the impact on technology adoption than any other outcome. The majority of studies (80%) reported increased technology adoption from ICT interventions, particularly for simpler agronomic practices. SMS, apps, video, and voice calls facilitate timely, personalized guidance to support farmer decision-making (Aker et al., 2016; Cole & Fernando, 2021). However, basic tools like radio did not reliably change complex behaviors, aligning with evidence that passive media struggle to shift deep-rooted practices (Fabregas et al., 2019). Adoption success also depends on digital literacy and access to complementary inputs, as Aker and Ksoll (2016) found in Nigeria. Overall, ICTs demonstrate promise in promoting technology use but require needs-based message design and enabling conditions to generate impact.

There is substantial evidence that ICTs can increase crop yields, with 74% of studies reporting productivity gains from tools such as SMS, apps, and video. For example, personalized nutrient management advisories via apps raised yields by 8-10% across multiple countries (Aker et al., 2016). However, 26% of the studies lacked yield impacts, often stemming from phone ownership or radio interventions that provided limited content. ICTs have difficulty improving productivity in isolation – access to inputs, training, and follow-up support are critical complements (Baumüller, 2018; Benin, 2017). However, multimedia tools and targeted messaging show particular potential to advance cultivation techniques at scale.

Although few studies have focused on the impact on income, the results offer interesting insights. The majority of studies (68%) found that ICT interventions increased farmer incomes by providing timely production and market information. Phones, SMS, and calls connect farmers to prices and buyers, aligning planting and sales with demand (Okello et al., 2020). However, 32% reported no income changes, as standalone information often fails to alter outcomes. For example, Rengaraj and Shibu (2020) found information insufficient without access to credit and inputs. While ICTs present income opportunities through reduced costs and post-harvest losses, holistic solutions bundling technology, training, and market linkages are essential to deliver livelihood benefits.

Applying Kleine's Choice Framework to these findings reveals that ICT-based interventions have the potential to expand farmers' choices at multiple levels. Mobile apps and SMS services increase the 'existence of choice' by providing access to a wider range of information and services. However, challenges such as limited digital literacy can affect farmers' 'sense of choice', highlighting the importance of user

training and support. The mixed results in adoption rates and yield improvements suggest that while ICTs can facilitate the ‘use of choice’, other factors such as access to inputs and markets also play crucial roles. Income improvements represent the ‘achievement of choice’, but our review shows that this outcome depends on comprehensive approaches that simultaneously address multiple dimensions of choice.

#### **4.2. Remaining challenges with ICTs use in agriculture**

ICT has had a substantial impact on sustainable agricultural development in underdeveloped nations through the use of various ICT tools. However, a number of problems and difficulties prevent the proper application of ICT in agricultural activities from bearing fruit. One study found that the usage of technology and, to a lesser extent, the provision of services were influenced by socioeconomic characteristics, such as gender, age, and education (Tata & McNamara, 2018). The study also reported a number of difficulties associated with using the technology, including missing agricultural records, low farmer literacy, software issues, and insufficient technical assistance (Tata & McNamara, 2018). Another study also identified the following challenges: a lack of fundamental ICT skills, a lack of political will, insufficient power, poor Internet infrastructure, a lack of awareness, particularly among rural farmers, a lack of local language content on the Internet, a lack of staff to manage ICT facilities, and a lack of knowledge harmonization (Saidu et al., 2017).

Other factors that contribute to the lack of success for some ICTs, and remain as potential challenges include (a) Limited user capabilities and support – Several studies like Aker and Ksoll (2016) found information provision alone insufficient without building farmers’ abilities to interpret and apply advisories. Lack of digital literacy and training constrains the impact, even with access to phones and apps (Cole & Fernando, 2021). Implementing new practices requires comprehensive educational processes and not just technology insertion (Singh et al., 2018). (b) Missing complementary interventions: In cases like Rengaraj and Shibu (2020), ICT tools lacked impact when farmers lacked access to inputs, credit, markets, or infrastructure to implement recommended practices. Standalone information cannot resolve systemic failures in enabling systems (Benin, 2017). Bundling services and taking an integrated approach are vital. (c) Inappropriate message design and delivery: The limited interactivity of tools such as SMS, radio, and passive videos makes sustained behavior change difficult compared to formats enabling two-way dialogue (Fabregas et al., 2019). Customizing content to users’ knowledge levels, decision schedules, and local contexts is essential, but not always done (Baumüller, 2018). (d) Endogenous and exogenous factors: The success of ICT interventions may be influenced by factors external to the technology itself, such as farmers’ existing knowledge and practices, socioeconomic conditions, and local agricultural practices. In some cases, the existence of agroecological stresses (e.g. droughts, floods, pests), socio-cultural dynamics, and gender inequalities in some areas may prevent the adoption of practices, even if successfully promoted through ICTs (Steinke et al., 2021). Accounting for these factors and tailoring interventions accordingly can enhance their effectiveness. (e) Lack of sustainability for most projects promoting ICTs: Many pilots rapidly expanded but lacked resources and plans for long-term sustainability, leading to lapses in services (Wyche & Steinfield, 2016). Institutionalization within public and private systems is critical.

### **5. Conclusion and recommendations**

Through the lens of Kleine’s Choice Framework, our review demonstrates that ICT-based extension services have the potential to expand smallholder farmers’ choices and capabilities. However, realizing this potential requires attention to all dimensions of choice, from ensuring the existence of relevant, accessible information to supporting farmers in achieving desired outcomes. Future research should further explore how different ICT interventions influence each dimension of choice and how these interventions can be designed to maximize farmers’ agency and well-being. Below, we offer concluding suggestions and recommendations to optimize the effectiveness of ICTs in agriculture.

### **5.1. How can we improve the effectiveness of ICTs in agriculture?**

Solving some of the above-highlighted issues is key to achieving the maximum impact. To ensure successful innovation spread, a balance must be maintained between the time and effort put into ICT design and other social elements, such as language and cultural norms (Aleke et al., 2011). Future studies should investigate how much ICTs can complement, as opposed to replacing conventional extension methods and farmer-to-farmer learning. In one case study, Namyanya et al. (2022) demonstrated how smartphone applications, such as e-diaries, can strengthen accountability in agricultural extension services by enabling remote supervision and real-time reporting. However, there is limited understanding of this and how it can be incorporated into the overall structure of extension. There is also a need to measure the actual use and farmer engagement with the messages delivered through ICT, for example, how much time farmers spend in the app, how much time farmers spend reading the messages, and the associated comprehension. We suspect that a combination of lack of detailed engagement, low digital literacy, and comprehension challenges associated with literacy is responsible for the non-significant impact on awareness or knowledge. Some studies suggest that extension-agent-assisted use of ICTs could contribute to overcoming barriers such as low (digital) literacy and lack of engagement. For example, Cole and Fernando (2021) found that lack of follow-up training and support constrained the impact of smartphone-based nutrient management apps in Gujarat, India, and suggested that combining ICT with public and private extension can boost success. Gandhi et al. (2007) evaluated mobile-based farmer helplines in India and found adding human intermediaries to offer training and interpretation increased usage and crop revenues while Mittal & Tripathi assessed mobile-based agricultural advisory system and found supporting farmers in setting up and using the app was crucial for adoption. Overall, the evidence indicates that while ICTs have the potential for remote advisory services, complementary training and support from public/private extension maximizes the impact by building farmers' capabilities and engagement. Therefore, the blended extension approach is recommended.

Other more general recommendations to improve the performance of ICTs include (a) Matching ICT design to users' needs, capabilities, and contexts—customizing messaging, platforms, and delivery to local languages, knowledge levels, decision schedules, infrastructure access, and cropping systems is essential for relevance and feasibility (Aker et al., 2016; Arouna et al., 2021). One-size-fits-all approaches often fail. (b) Bundling ICT with training, peer learning, and complementary services—information alone is insufficient—farmers need capabilities and resources to implement new practices (Cole & Fernando, 2021; Benin, 2017). ICTs should integrate digital literacy building, social learning, and links to inputs, credit, markets, etc. (c) Prioritize interactive multimedia formats—apps, advisory services, and videos outperform passive SMS and radio by enabling nuanced back-and-forth exchanges and engagement (Fabregas et al., 2019; Mittal et al., 2012). However, the design must still align with user preferences. (d) Facilitating two-way user feedback loops—user feedback on challenges and suggestions during implementation enables rapid learning and adaptation of message design, platforms, troubleshooting of problems, and targeting (Fabregas et al., 2023). (e) Participatory design: Engaging farmers and other stakeholders in the design and development of ICT interventions can lead to more relevant and effective solutions. Participatory approaches ensure that the technology meets the real needs and preferences of end-users.

### **5.2. Contribution to IT for development**

This systematic review makes several contributions to the field of IT for development. For academics, our findings provide a comprehensive synthesis of evidence on the impact of ICT-based extension, highlighting key patterns, moderating factors, and remaining knowledge gaps. Future research should address the key gaps and contradictions identified in this review. First, given the mixed results on knowledge and awareness outcomes (e.g. Dzanku et al., 2022 vs. Mohammed & Abdulai, 2022), studies should investigate the factors influencing ICT's effectiveness in information

dissemination, such as message design and delivery methods. Second, research is needed to understand why some ICT interventions fail to impact yields or income (e.g. Chua et al., 2021; Cole et al., 2020), exploring potential barriers to translating information into practice. Finally, given the success of multimedia formats (Van Campenhout et al., 2021), research should explore optimal combinations of ICT tools to maximize the impact across different agricultural contexts and farmer demographics. These efforts will contribute to more effective and tailored ICT-based extension services.

The second aspect for academicians is that there is a need for a comprehensive framework to understand how ICTs interact with smallholder farmers to produce varied outcomes. Future theoretical advancements could integrate elements of the Technology Acceptance Model (Davis, 1989) with Kleine's Choice Framework (Kleine, 2013) and the Sustainable Livelihoods Approach. This integrated framework can better capture how farmers' capabilities, assets, and local contexts interact with ICT interventions to produce varied outcomes. Furthermore, future research could consider socio-technical design principles for multi-stakeholder agricultural information systems (Atinaf et al., 2024) that engage in plying social and technical aspects to optimize the benefits for certain social classes of farmers.

For practitioners, insights into successful ICT tools, complementary support, and implementation challenges can inform the design and deployment of digital extension initiatives. By identifying the best practices and areas for improvement, our review can help optimize the use of ICTs to advance smallholder development outcomes.

In conclusion, while ICTs show considerable promise in driving agricultural development outcomes, they are complements to, not substitutes for, strong human and institutional capacities. As digital technologies continue to expand in rural areas, it is crucial to build on these insights, addressing identified research gaps and contradictions, to ensure that ICT interventions effectively serve the needs of smallholder communities and create equitable, sustainable pathways for agricultural development.

Finally, this systematic review has several limitations worth noting. First, despite our comprehensive search strategy, we may have inadvertently omitted relevant studies, particularly those published in languages other than English. Second, the heterogeneity in the outcome measures and methodologies across the included studies made direct comparisons challenging, potentially limiting the precision of the conclusions. Finally, our review focused primarily on quantitative outcomes, which may not fully capture the nuanced, qualitative impacts of ICT interventions on farmers' decision-making processes and social dynamics. These limitations underscore the need for cautious interpretation of our findings and highlight areas for improvement in future research in this field.

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## Appendix

**Table A1.** Summary of studies, type of ICTs, agricultural technology, and findings on the impact on knowledge/awareness.

no	Author	Type of ICT	Practice/ Technology	Findings	Impact?
1	(Campenhout, 2021)	Video	Crop Management	Positive impact on technical knowledge related to time to transplant, and straw management but not on fertiliser	Yes
2	(Van Campenhout et al., 2021)	Video	Crop Management	Only significant effect on input combination and optimal spacing for one treatment out of three. The rest (9 estimations) were not significant.	No
3	(Cole et al., 2020)	Voice calls	Nutrient Management	Significant effect on knowledge about fertiliser use, for all four different estimations	Yes
4	(Dzanku et al., 2022)	Video	Nutrient Management	All estimations for both video and radio listening club had no effect on knowledge of inoculant technology	No
		Radio	Nutrient Management		No
5	(Fu & Akter, 2016)	General	Crop Management	Increased knowledge of agricultural practices	Yes
6	(Lasdun et al., 2022)	SMS	Sustainable Agricultural Practices	No effect on increase in overall knowledge and practice specific knowledge	No
7	(Mohammed & Abdulai, 2022)	General	Nutrient Management	Significant impact on knowledge scores between those who used the ICT-based extension and those who did not	Yes
8	(Nakasone & Torero, 2016)	Video	Pest Management	Significant effect on knowledge from all six different estimations	Yes
9	(Fisher et al., 2019)	Phone ownership	Improved Seeds	Positive effect of electronic media on drought tolerant maize awareness from both models	Yes
10	(Fabregas et al., 2019)	SMS	Nutrient Management	Positive effect on awareness and knowledge only 8 out of the 16 regressions	No

**Table A2.** Summary of studies, type of ICTs, agricultural practice/ technology, and findings on the impact on knowledge/ awareness.

no	Author	Type of ICT	Practice/ technology	Findings	Impact
1	(Djido et al., 2021)	SMS & Voice calls	Sustainable Agricultural Practices	Significant impact on the adoption of water conservation and multiple cropping practices. No statistical significance on the adoption rates of erosion control, pest-resistant crops, and integrated pest management.	Yes No
2	(Aminou et al., 2018)	App	Nutrient Management	Personalised advice on nutrient management had no positive effect on the quantity of fertiliser used by farmers.	No
3	(Dzanku et al., 2021)	Voice calls	Post-Harvest	Voice call reminders significantly induced timely harvesting, reduced on-farm cereal losses, increased uptake of improved grain storage technology and increased the likelihood of preharvest sales contracting.	Yes
4	(Dzanku et al., 2022)	Video & Radio	Nutrient Management	Positive impact on the uptake of inoculants by farmers in the entire sample who used the technology	Yes
5	(Dzanku et al., 2022) (Naik & Krishna, 2021)	Video & Radio App	Improved Seeds Sustainable Agricultural Practices	A positive effect recorded on the use of the improved seeds at end line for the entire sample. A significant reduction in the quantity of nitrogen and phosphorous used by the farmers – reduced wastage	Yes Yes
6	(Aker & Ksoll, 2016)	App	Crop Diversification	No impact on the likelihood of households cultivating most staple food and cash crops, such as millet, sorghum, cowpea or sesame. Statistically significant impact on households cultivating okra than those in non-intervention villages.	No
7	(Oyinbo et al., 2022)	App	Nutrient Management	Treatments increased the likelihood of adopting combined use of inorganic fertiliser and manure	Yes
8	(Asad, 2015)	Phone ownership	Crop Diversification	Access to cell phone coverage increased the probability of growing extremely and highly perishable crops; farmer coordinating an advanced sale date with trader for the extremely perishable crops; decreased the gap between actual date and the optimal period of plantation.	Yes
	(Asad, 2015)	Phone ownership	Crop Diversification		Yes
9	(Sennuga et al., 2020)	SMS	Crop Management	ICT (SMS text reminders) had positive impact on the adoption and implementation of recommended GAP technologies.	Yes
10	(Cole et al., 2020)	Phone ownership	Nutrient Management	A significant impact on the adoption of recommended fertilisers,	Yes
10	(Sharma et al., 2021)	SMS	Crop Management	Positive impact on the timing of all three operations – farmers irrigate their field closer to the date when it is scheduled; apply urea closer to the scheduled dates for the treatment group; apply weedicide closer to the scheduled dates for the treatment group.	Yes
11	(Lasdun et al., 2022)	SMS	Sustainable Agricultural Practices	Group chats on app led to a significant effect on adoption of intercropping with a legume on their main maize plot. No significant effect on the production or application of organic fertilisers on the fields.	No
12	(Gupta et al., 2020)	Voice calls	Improved Seeds	Farmers in areas with mobile phone coverage had an increased uptake of HYV seeds between 2007 and 2012.	Yes
13	(Casaburi et al., 2014)	SMS & Voice calls	Nutrient Management	Access to the farmer hotline had a positive impact on farmers receiving fertiliser for their farms timely and reduced the likelihood of any delay in fertiliser delivery	Yes

(Continued)

**Table A2.** Continued.

no	Author	Type of ICT	Practice/ technology	Findings	Impact
14	(Mohammed & Abdulai, 2022)	Computer	Nutrient Management	ICT had no significant impact on getting farmers to adopt a new technology (Bradyrhizobium inoculant)	No
15	(Mittal & Tripathi, 2009)	App	Improved Seeds	ICT had a positive and significant impact on the use of purchased seed per acre, purchased fertiliser per acre.	Yes
16	(Hou et al., 2018)	General	Labour Management	Ownership of computer and access to the Internet, led to larger rented land size and reduction in family labour man-days, also a clear significant effect on market participation identified.	Yes
17	(Larochelle et al., 2019)	SMS	Integrated Pest Management	Significant impact on the use of IPM	Yes
18	(Chua et al., 2021)	App	Sustainable Agricultural Practices	Positive impact recorded on farmers who watched technical videos compared to those who watched aspirational videos	Yes
19	(Li et al., 2022)	App	Nutrient Management	The use of the APP increases the adoption of soil testing and formula fertilisation.	Yes
20	(Maredia et al., 2018)	Video	Post-Harvest	The video-based training method had a positive impact on the adoption of triple bag technology. The video-based training had no significant effect on the adoption of solar disinfestation technology due to it being a new technology to the participants unlike the triple bag technology.	No
21	(Kiiza & Pederson, 2012)	General	Improved Seeds	ICT had a positive impact on the share of improved seed used compared to total amount of seed planted by farmers	Yes
22	(Tambo et al., 2019)	SMS, Radio & Videos	Integrated Pest Management	Positive and significant effect on the adoption of Fall Army Worm management practices.	Yes
23	(Fafchamps & Minten, 2012)	SMS	Crop Management	Significant change in number of farmers who changed their crop variety. Treated farmers more likely to switch from farm-gate to market sale. Treatment raises the proportion of farmers grading or sorting their output	Yes
24	(Vasilaky et al., 2015)	Video	Crop Management	Probability of adoption increased among farmers who viewed the videos.	Yes
25	(Fu & Akter, 2016)	Phone ownership	Labour Management	Positive impact of ICT on the quality of the extension services for farmers. The technology also helped to deliver the services quickly.	Yes

**Table A3.** Summary of studies, type of ICTs, agricultural practice/ technology, and findings on the impact on yield.

no	Author	Type of ICT	Practice/ technology	Findings	Impact
1	(Arouna et al., 2021)	App	Nutrient Management	Yield increased among households who were given the personalised advice	Yes
2	(Subramanian, 2021)	SMS & Voice calls	Integrated Pest Management	Hotlines are associated with a significant increase in crop yields.	Yes
3	(Campenhout, 2021)	Video	Nutrient Management	Yields higher among households in the video treatment than among the control group.	Yes
4	(Dzanku et al., 2021)	Voice calls	Post-Harvest Practices	No evidence of impact on yield	No
5	(Dzanku et al., 2022)	Radio	Nutrient Management	legume yields increased between baseline and follow-up as a result of ICT intervention.	Yes
	(Mwalupaso et al., 2020)	Voice calls	Nutrient Management	Positive increase in yield recorded.	Yes
6	(Naik & Krishna, 2021)	App	Nutrient Management	The project led to a significant increase in returns for the paddy farmers and cotton farmers at the end of two years of intervention.	Yes
7	(Zheng & Ma)	App	Sustainable Agricultural Practices	Farmers who acquire information via smartphones were able to obtain higher wheat yields than their counterparts who did not acquire the information.	Yes

(Continued)

**Table A3.** Continued.

no	Author	Type of ICT	Practice/ technology	Findings	Impact
8	(Sennuga et al., 2020)	SMS	Crop Management	Farmers experienced an increase in the productivity of their crops as a result of the ICT	Yes
9	(Oyinbo et al., 2022)	App	Sustainable Agricultural Practices	Positive impact on the reduction of GHG emissions per unit maize yield compared with the control group.	Yes
10	(Oyinbo et al., 2022)	App	Nutrient Management	Interventions led to statistically significant increases in maize yield	Yes
	(Quandt et al., 2020)	SMS	Nutrient Management	Interventions did not lead to any significant increases in maize yield	No
11	(Yegbemey et al., 2021)	SMS	Weather And Climate Information	Providing smallholders with weather-related information through mobile phone SMS had a positive effect on yield.	Yes
12	(Asad, 2015)	Phone ownership	Post-Harvest Practices	Access to cell phone coverage increased yield	Yes
13	(Sennuga et al., 2020)	SMS	Sustainable Agricultural Practices	Respondents experienced rapid increases in their crops productivity due to the availability of credible information through SMS text reminders received fortnightly.	Yes
14	(Cole et al., 2020)	Phone ownership	Nutrient Management	No evidence of a change in yields recorded.	No
15	(Das et al., 2017)	General	Sustainable Agricultural Practices	ICTs had a positive impact on the production of two rice (Boro and Broadcast Aman), potato, wheat, maize and pulse (lentil).	Yes
16	(Ali et al., 2016)	General	Nutrient Management	The production per acre of farmers using television had higher production per acre due to telecast of different programmes on use of seed, fertiliser and other techniques of production in agriculture.	Yes
17	(Umaroh & Afifah, 2020)	Phone ownership	Sustainable Agricultural Practices	Use of mobile phones had a positive impact on the productivity of rice farmers compared to those who do not use mobile phones	Yes
18	(Sharma et al., 2021)	SMS	Weather And Climate Information	The SMS agri-met advisories intervention did not have a significant effect on the yield of the farmers	No
19	(Lasdun et al., 2022)	SMS	Sustainable Agricultural Practices	No statistically significant effect on yields.	No
20	(Yegbemey et al., 2021)	SMS	Weather And Climate Information	The intention to treat effect suggests an increase of 461 kg/ ha, roughly 10% higher than control group mean	Yes
21	(Gupta et al., 2020)	Voice calls	Improved Seeds	Farmers with access to information experienced a larger increase in agricultural productivity.	Yes
22	(Rengaraj & Shibu, 2020)	Radio	Improved Seeds	The impact of radio through seed and fertiliser on profit per acre was not significant	No
23	(Aminou et al., 2018)	Phone ownership	Nutrient Management	Mobile phones adoption enhanced agricultural productivity.	Yes
24	(Umadikar et al., 2014)	Voice calls	Weather And Climate Information	Significant increases in yield recorded	Yes
25	(Casaburi et al., 2014)	SMS & Voice calls	Nutrient Management	Access to the SMS project raises yields significantly	Yes
26	(Otter & Theuvsen, 2014)	App	Sustainable Agricultural Practices	Positive impact on the productivity of the smallholder raspberry farms.	Yes
	(Otter & Theuvsen, 2014)	App	Sustainable Agricultural Practices	Negative impact on the productivity of the table grape producers.	No
27	(Mohammed & Abdulai, 2022)	Computer	Nutrient Management	Yields increased significantly for ICT intervention groups.	Yes
28	(Singh et al., 2018)	Voice calls	Crop Management	Intervention contributed to a bumper cotton crop in north India	Yes

(Continued)

**Table A3.** Continued.

no	Author	Type of ICT	Practice/ technology	Findings	Impact
29	(Chua et al., 2021)	Video	Crop Management	Farmers who watched aspirational videos did not gain any increase in their income levels.	No
30	(Kiiza & Pederson, 2012)	General	Improved Seeds	A statistically significant increase in average yields after adoption of improved seed is recorded.	Yes
31	(Fafchamps & Minten, 2012)	SMS	Weather And Climate Information	There was no evidence that weather forecasts increase yields	No
32	(Nikam et al., 2022)	Radio	Improved Seeds	Access to any one formal source of information through radio led to a yield advantage compared to the farmers who did not have access to any formal source of information.	Yes

**Table A4.** Summary of studies, type of ICTs, agricultural practice/ technology, and findings on the impact on knowledge/ awareness

no	Author(s)	Type of ICT	Practice/ technology	Findings	Impact
1	(Asad, 2015)	Phone ownership	Market And Price Information	access to cell phone coverage decreased the percentage of price lost for all the crops, increasing agricultural income	Yes
2	(Yegbemey et al., 2021)	SMS	Weather And Climate Information	providing smallholder farmers with weather-related information through mobile phone SMS may have a positive effect on farm income.	Yes
3	(Rengaraj & Shibu, 2020)	Voice calls	Nutrient Management	The impact of seed and fertiliser on profit per acre was not significant	No
4	(Chua et al., 2021)	App	Water Management	Farmers who watched aspirational videos did not gain any increase in their income levels.	No
			Nutrient Management	Farmers who watched aspirational videos did not gain any increase in their income levels.	No
			Pest Management	Farmers who watched aspirational videos did not gain any increase in their income levels.	No
5	(Okello et al., 2020)	Phone ownership	Market And Price Information	Participation in ICT intervention increased income earned by farmers	Yes
6	(Khan et al., 2022)	Phone ownership	Market And Price Information	Significant increase income for households that actively used mobile phones and internet technology	Yes
7	(Umadikar et al., 2014)	Voice calls	Weather And Climate Information	Quantity of chemical fertilisers applied was reduced, bringing down the costs of inputs, and increasing income	Yes
8	(Aminou et al., 2018)ce	Phone ownership	Nutrient Management	The maize selling price was higher for those with phones	Yes
9	(Haile et al., 2019)	Phone ownership	Weather And Climate Information	Farmers who own cell phones and who reside closer to grain markets have smaller price forecasting errors	Yes