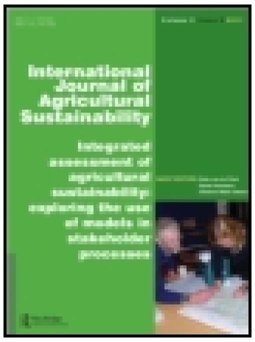

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Tapping the full potential of the digital revolution for agricultural extension: an emerging innovation agenda

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ABSTRACT
Agricultural extension in the Global South can benefit greatly from the use of modern information and communication technologies (ICT). Yet, despite two decades of promising experiences, this potential is not fully realized. Here, we review the relevant research literature to inform future investments into agricultural information services that harness the full potential of digital media. We describe a recently emerging innovation agenda that is, in part, a response to the eventual failure of many new agro-advisory initiatives. One important cause of failure has been a focus on pushing certain technologies, rather than responding to the particular communication challenges of potential users. To avoid such bias in designing new services, the new innovation agenda rests on two major foundations: strong user-centredness and problem-orientation. In our review, we first describe how user-centred design methods help in specifying both problems and (digital) solutions in agricultural extension. To inform responses to the communication challenges defined by that analysis, we then describe eight emerging aspects of using ICT for development, and how they can address common deficiencies of agricultural extension. Practical examples from the literature highlight the possibilities and limitations of these innovation directions. Beyond digital design, however, technological innovation requires enabling institutions.

KEYWORDS
Agricultural extension; ICT; digital feedback; user-centred design; crowdsourcing; digital innovation

1. Introduction

Recent technological development has generated high expectations about the future role of modern information and communication technologies (ICT) for agricultural advisory services in smallholder farming context (Aker et al., 2016; Deichmann et al., 2016). Interest in improving agricultural extension by digital media is high because established methods, such as Training-and-Visit or Farmer Field Schools, have not always achieved desired outcomes in terms of technology adoption or livelihood improvements (Faure et al., 2012; Taye, 2013). Many of the current limitations of agricultural advisory (agro-advisory) services are due to imperfect information flows between the stakeholders of a complex knowledge system, including farmers, traders, processors, extension agents, and researchers (Faure et al., 2012). But widespread access to mobile telephones has created new possibilities to support these information flows. In contrast to traditional mass media (such as radio, television, posters), mobile phones allow farmers to actively engage in more sophisticated information exchange through two-way communication. Therefore, it is expected that more intensive use of modern ICT can help to improve

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the performance of agricultural extension (Duncombe, 2015; Nakasone & Torero, 2016). Examples of new digital agro-advisory services include SMS-based market information services, call centres for technical farm advice, facilitation of farmer-to-farmer knowledge sharing via participatory video, or decision support systems implemented as smartphone apps (Aker, 2011; Aker et al., 2016; Baumüller, 2018).

The first decade of experience with digital agro-advisory services for smallholder farmers has, however, demonstrated that ICT solutions are not a panacea. Effects on farmers' decision-making have often been weak (Baumüller, 2018; Nakasone et al., 2014). Digital advisory applications have frequently suffered from a lack of feedback mechanisms and mismatches with farmers' information needs, their technological capabilities and habits, timing of information delivery, or insufficient trust in information sources (Aker et al., 2016; Fabregas et al., 2019; Sulaiman et al., 2012; Wyche & Steinfield, 2016). These shortcomings have led to the discontinuation of many services after initial funding ended, as they did not succeed to sufficiently engage policymakers or to develop into viable business models (Qiang et al., 2012).

The literature on ICT for development (ICT4D) attributes the often-disappointing performance of digital information services to 'design-reality gaps': design processes for new information services are often centred around specific technologies and informed by strong technological rationality (Heeks, 2002). As a result, the features of new ICT4D services tend to be based on flawed assumptions about the reality of users, including their information needs and technology use preferences (Dodson et al., 2013; Masiero, 2016). These experiences suggest that: Firstly, the development of digital advisory applications should be based on co-design with diverse future users to develop solutions that address the needs and perspectives of local stakeholders (user-centredness). Secondly, the choice of technology should be driven by an analysis of the communication challenges affecting agricultural extension services, rather than by the possibilities of particular digital technologies (problem-orientation).

To put these two principles into practice, a new research and design agenda for digital agricultural extension is already taking shape in recent work. The goal of this paper is to describe emerging concepts that contribute to this agenda, and to inform the design of new digital advisory services by illustrating their possibilities and limitations.

2. User-centred design of digital agro-advisory services

The first pillar of the new digital innovation agenda for agricultural extension is an increased use of user-centred design approaches. This is a recent development: in the past, many digital information services in low- and middle-income countries were created by technology enthusiasts with a promising idea. Often, funding came from international donors, which demanded a well-planned service design *before* paying for its implementation (Dodson et al., 2013). This focus on proof-of-concept studies has caused many novel services to suffer from overly rigid pre-planning, where developers determined the technological options prior to intense interaction with the targeted user groups. Such rigid pre-planning has frequently hindered subsequent, flexible adaptation of the original ideas in interaction with prospective users, and thus contributed to failure (Dodson et al., 2013; Heeks, 2002). In practice, however, new insights about local information needs, user preferences, and capacities often arise during the design process and challenge the initial assumptions. The use of participatory design methodologies involves iterative feedback cycles during the specification of solutions (Tongia & Subrahmanian, 2006).

User-centred design of products and services predates the emergence of digital agro-advisory applications (Norman, 1988). Now, multiple user-oriented design methodologies for the development sector exist, often referred to as 'human-centred design' (Bazzano et al., 2017). For example, global design company IDEO provides a comprehensive approach for developing tools and services together with users (IDEO.org, 2015). This design process consists of three steps: (1) Inspiration: getting to know the design challenge and the prospective users, (2) Ideation: co-creating tentative tools and services with users in rapid iterative cycles, and (3) Implementation: testing and refining design prototypes in a real-life context. A recent use case of user-centred design for agricultural information services is described in Box 1.

Stimulating user feedback at early stages of the development of new digital applications is essential. This ensures that the developed services meet users' actual communication and information needs and provide an easy and appealing user experience. Ongoing, iterative testing of draft designs with farmers and other stakeholders (see Figure 1) may generate important insights into which type of

Box 1. Developing a digital information service through user-centred design.

In 2018 and 2019, researchers from Bioversity International adapted IDEO's Human-Centered Design methodology (see Section 2) to develop a digital agro-advisory service in Tanzania (Ortiz-Crespo et al., 2020). In the 'Inspiration' phase, interviews with smallholder farmers and extension agents generated information about current challenges and preferences around information flows in agricultural advisory. Extension agents stated being overburdened with telephone calls by farmers, at times being unable to pick up calls. It was found that many farmers enjoyed agricultural radio shows, but often missed them or found them irrelevant. In the 'Ideation' phase, the design team used these insights to generate a design concept: an automated telephone hotline providing on-demand audio content should answer farmers' most common questions. The same hotline would record farmers' additional questions. Advisors should thereby have fewer questions to answer overall, as frequent issues would already have been dealt with by the existing, recorded audio contents. In prototyping sessions with farmers and advisors, these ideas were shared, discussed, and 'simulated', for example, by acting out different types of interactive voice response (IVR) menus (cf. Figure 1). The design was further specified based on users' ideas, opinions, and their observed behaviors in the simulations. In the 'Implementation' phase, a working service prototype was created and tested for a predefined period of time with a group of farmers and advisors. The pilot revealed the need for further modifications to the service.

information service is actually desirable, what a proposed service might be used for, and which types of user interactions and technologies work best (Boersma, 2017). Continuously eliciting user feedback is crucial to identify solutions that are appropriate for the local context, including literacy levels and the availability of mobile phones, electricity, or other technical infrastructure. Useful feedback can be generated by exposing future users to rough sketches and unfinished products, avoiding mistakes that are more costly to correct when designs are already highly specified (Gulliksen et al., 2003; Snyder, 2003). At later stages, iterative testing of prototypical designs with different stakeholders may refine the user experience. This ensures that services are easily understood, audio-visually attractive, affordable, and fit in with daily routines (Hassenzahl & Tractinsky, 2006; Wyche & Steinfield, 2016).

3. Common challenges for agricultural extension services

The second pillar of the emerging innovation agenda is a strong focus on the specific problems affecting the performance of agricultural extension. Instead of looking for use cases for certain technological innovations, prospective designers of new services need to interact closely with farmers and agricultural advisors to identify existing deficiencies of extension, which may vary greatly by context. To support the subsequent, informed selection of technological solutions, this section provides an overview of common communication challenges in agricultural extension services (see Table 1). Following an established framework for analyzing agricultural extension systems (Anderson & Feder, 2004), we describe key challenges, grouped by the three main stakeholder groups relevant to extension services: (1) scale and complexity (farmers), (2) weak alignment with research activities (researchers), and (3) lack of evidence on outcomes (policy-makers and donors). A fourth major challenge relates to the dependence of the extension system on the wider policy environment.

Scale and complexity. Agricultural extension services must often reach a large and widely dispersed farming population characterized by diversity in opportunities, constraints, individual aspirations, and consequently, information needs. But public and private extension services often lack the resources required to adequately address this diversity through conventional extension approaches. Important restrictions include limited staff time and the transportation costs associated with farm visits and individual face-to-face interactions. As a result, advisory services often resort to broadcasting relatively generic advice to the heterogeneous farming population or count on horizontal spillover effects from a focus on few, often larger and better-endowed households (Feder et al., 2010; Taylor & Bhasme, 2018). These types of biased rationing often mean that the quantity and quality of advisory contacts are compromised especially for the poorest farmers, women, and spatially remote households.

Weak alignment with research activities. Agricultural research and agricultural advisory are often carried out by separate organizations, under separate governance, and with different goals (Davis, 2008). For example, research organizations may aim for publication output, while extension services follow a specific technology transfer agenda. As a result, research priorities do not always correspond with the information needs of farmers or extension staff. In turn, potentially beneficial research outputs are not always widely disseminated by the advisory services (Belay, 2002). The differences in governance and incentives often hinder the much-needed transition from mostly linear to more systemic approaches

Figure 1. 'Testing IVR-style interaction with farmers using flashcards' (Figure reproduced with permission from Patel et al., 2010). Early-stage prototyping activities with target users, before investing into actual software programming, may generate crucial insights into communication needs, habits, and preferences.

in knowledge generation and dissemination (Klerkx et al., 2012).

Lack of evidence on outcomes. It has been challenging to attribute changes in farmers' decision-making, farm performance, and livelihoods to the activities of agricultural extension (Knook et al., 2018; Taye, 2013). This means that, firstly, advisory staff is not evaluated consistently on the basis of their performance. Therefore, they are rarely incentivized to improve the effectiveness of their advice (Davis, 2008; Jones & Kondylis, 2018). Secondly, extension services hardly produce robust evidence on effects, aside occasional impact evaluations. Consequently, policy-makers can be inclined to shift funds to other sectors that demonstrate a more evident return-on-investment (Anderson & Feder, 2004; Anderson et al., 2006). To achieve policy outcomes that are more visible, public advisory staff are often charged by their supervisors with tasks that relate to other public duties, such as collecting statistics or distributing inputs (Anderson & Feder, 2004; Belay, 2002). The absence of simple and reliable mechanisms for reporting activities and effects of agricultural extension to policy-makers causes unreliable funding. This, in turn, further weakens the actual potential for positive outcomes.

Dependence on the broader policy environment. The effectiveness of agricultural extension will often depend on institutions and political decisions that are not directly linked to the knowledge dissemination sector. Examples include the regulations governing credit availability, subsidies for agricultural inputs, or taxes on agricultural trade. In addition, political and organizational cultures inside the extension system, such as strong hierarchies, can affect how extension agencies learn, build capacities, and embrace necessary organizational change (Müller et al., 2019; Rivera, 2011). Given that these aspects are difficult to influence directly through digital design, we will explore this point further in Section 5.

4. Eight recent innovation directions to address communication challenges

4.1 Scaling information delivery due to lower per-unit cost of dissemination

Many extension services worldwide employ ICT, including radio and television, to rapidly disseminate information to a broad audience. Mass dissemination of agricultural information with little contextual

Table 1. Major challenges affecting the performance of agricultural extension services, and recent innovation directions for responding to these challenges through increased use of modern ICT.

Communication stakeholder	Major challenge	Analytical elements by Anderson and Feder (2004)[a]	Innovation direction	Examples of digital agro-advisory applications	See Section
Farmers	Scale and complexity	Scale and complexity	• Scaling information delivery due to low per-unit cost of dissemination	Esoko (Courtois & Subervie, 2015)	4.1
			• Tailoring advisory contents to individual users through two-way communication	AgroDecisor (Carmona et al., 2018)	4.2
			• Supporting farmer-to-farmer sharing of experiences	GeoFarmer (Eitzinger et al., 2019)	4.3
Researchers	Weak alignment with research activities	Interaction with knowledge generation	• Increasing client-orientation of research by crowdsourcing farmers' information needs	LifeLines (Haider Rizvi, 2011)	4.4
			• Supporting farmer experimentation and observation through agricultural citizen science	ClimMob (Van Etten et al., 2017, 2019b)	4.5
Policy-makers and donors	Lack of evidence on outcomes	Difficulty in attributing impacts; Weak accountability; Weak political commitment and support; Public duties other than knowledge transfer; Fiscal sustainability	• Monitoring and evaluation by analyzing usage data from digital services	Ushauri (Ortiz-Crespo et al., 2020)	4.6
			• Measuring impacts by remote household surveying integrated into advisory applications	*not fully implemented yet*	4.7
			• Increasing the accountability of advisory providers by crowdsourcing user evaluations within digital services	*no name (Hasanain et al., 2017)*	4.8

[a]An additional element and challenge, *Dependence on the wider policy environment*, was not included here, as it cannot be addressed directly by digital design (see Section 3).

adaptation can be appropriate in some cases, for example, for seasonal climate forecasts. Because delivering this type of information via ICT is cheaper than via visits by extension personnel, higher numbers of farmers can be reached by an information intervention with given resources (Aker, 2011). In addition, the use of digital communication can mitigate the geographic bias often observed with conventional face-to-face dissemination methods, which tend to concentrate on farmers living near large settlements or good roads.

In practice, however, farmers often miss radio or TV broadcasts because they are busy with farm labour or household chores, or because contents are perceived as irrelevant (Mwombe et al., 2014). New mobile phone-mediated services can address these limitations by enabling farmers to request the information they are interested in, at times that suit their individual availability (Baumüller, 2018). Self-selection of users through subscribing to certain types of messages allows matching information supply and demand on an individual basis. In Ghana, for example, farmers can sign up for the 'Esoko' service, which sends biweekly market price alerts via SMS. These notifications increased farmers' bargaining power, allowing them to negotiate higher farmgate prices for maize and groundnut (Courtois & Subervie, 2015).

Mobile applications can alleviate some spatial biases in the selection of extension targets. But access to mobile phones, as well as other ICT, is often unequally distributed (Aker et al., 2016; Blumenstock & Eagle, 2012). As a result, the use of mobile phones for agricultural information transfer can also aggravate information asymmetries between traders and farmers, wealthier and poorer farmers, or men and women. Inclusive scaling of extension activities thus implies the integration of digital communication within pluralistic advisory services that use different communication channels, including digital and analogue ones (Birner et al., 2009; Sulaiman et al., 2012).

In Tanzania, for example, a multi-channel 'campaign' approach to agricultural extension, integrating dissemination via interactive radio, SMS, field demonstrations, and other channels, led to higher uptake of promoted technologies than any channel alone (Hampson et al., 2018).

4.2 Tailoring advisory contents to individual users through two-way communication

Smallholder farming is characterized by strong diversity in biophysical conditions, input use, aspirations, and other dimensions. Extension services need to address this diversity, which can be done by delivering different advisory messages to different farmers. This is challenging with conventional extension formats that often aim at broad adoption of standardized technologies. Digital two-way communication via farmers' mobile phones allows the collection of data on individuals' households, farms, or even plots, which can then be used to select and return individually customized advisory contents. But to be useful in practice, data collection should demand very little time and effort from farmers (Rosenstock et al., 2017). Therefore, the advisory application must use household indicators that need little data but are at the same time predictive of farmers' information preferences or needs (Steinke et al., 2019). Viable implementations of this trade-off between rapidness of data collection and household-specificity of advice exist. For example, Carmona et al. (2015) have developed a simple scoring system that gives recommendations on pesticide application (apply/don't apply) based on plot-level answers to ten questions about farming practice, rainfall, the desired use of the produce, and other aspects (Figure 2). The system, targeted at commercial soybean farmers in Argentina, has been implemented as a smartphone application called 'AgroDecisor', where farmers input data and receive direct feedback (Carmona et al., 2018).

For more resource-poor smallholder context, similar smartphone apps for decision support exist but generally address extension agents, rather than the farmers. One such example is 'RiceAdvice', created by AfricaRice (riceadvice.info). In smallholder context, however, conventional mobile phones also

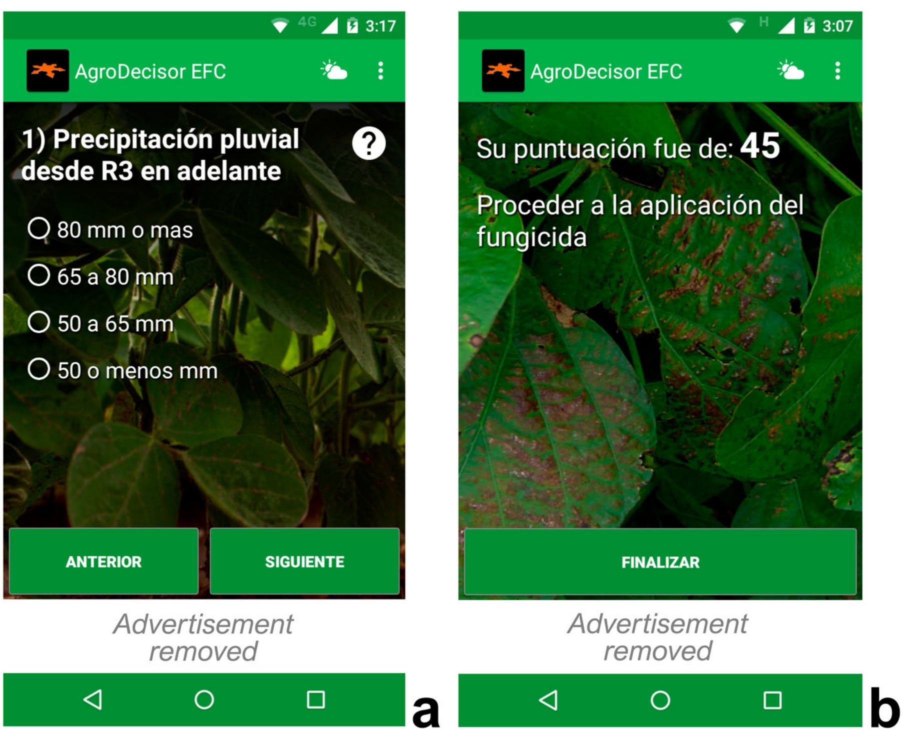

Figure 2. The 'AgroDecisor' smartphone application (Carmona et al., 2018) uses two-way communication to provide tailored advice: (a) Argentinian soybean farmers answer ten key questions, for example, about rainfall quantity. (b) The application calculates a plot-specific susceptibility score and gives a recommendation on fungicide application.

have the potential for users' autonomous data entry in two-way communication interfaces, for example, through unstructured supplementary service data (USSD) or IVR technologies (Patnaik et al., 2009). Hammond et al. (2017), for example, describe a modular household survey that was designed for simplicity, speed, and integration in digital applications (e.g. by avoiding open questions). In many low- and middle-income countries, recent developments in mobile money services imply that mobile phone users have become widely acquainted with short, automated data entry through USSD and IVR technologies (GSMA, 2017).

4.3 Supporting farmer-to-farmer sharing of experiences

Many agricultural advisory services treat farmers as recipients, not originators, of advisory contents. Farmers can, however, be more likely to act upon advice from peer farmers than from formal organizations, such as extension services (Hoffmann et al., 2007; Krishnan & Patnam, 2014; Patel et al., 2013). Thus, integrating different knowledge cultures (formal, informal, local, experiential) may be crucial for successful agricultural innovation processes (Šūmane et al., 2018). Mobile phone-mediated services can facilitate such integration. One example is the 'Ushauri' hotline (Ortiz-Crespo et al., 2020). In this automated hotline, farmers have access to pre-recorded advisory audio messages that compile information provided by agricultural researchers, extension staff, and experienced farmers.

Modern ICT offers many opportunities to collect, organize, and horizontally share knowledge inputs from farmers. For example, in 'Avaaj Otalo', a phone-accessible agro-advisory service from India, the most popular feature was a moderated voice-based discussion forum for the exchange of experiences and question-answering among farmers who would not otherwise meet in person (Patel et al., 2010). For technologically more advanced contexts, the 'GeoFarmer' system allows users to submit observations and questions via a smartphone application (Eitzinger et al., 2019). Other users can then comment, answer, or 'up-vote' contributions perceived as useful, and the service highlights best-voted contributions as best-practice.

These types of systems for peer-to-peer sharing of experiences may require careful supervision by extension staff, as farmers' successful experiences may not in all cases be applicable to other contexts. Thus, efforts for curation and explicit contextualization of farmers' contributions are likely indispensable. To incentivize the contribution of (accurate) answers to other farmers' questions, digital applications can award points and scores to individual registered users. This could eventually 'unlock' privileges in the extension system, such as becoming a farmer-to-farmer trainer. In non-farming contexts, point-based reputation systems are already widely established for encouraging knowledge exchange in voluntary online peer-to-peer advice fora such as *quora.com* or *stackoverflow.com*.

4.4 Increasing client-orientation of research by crowdsourcing farmers' information needs

Various participatory methodologies for involving farmers in agenda setting for agricultural research exist (Neef & Neubert, 2011; Schut et al., 2016). Yet in practice, the relative resource-intensity of these approaches and the difficulty of scaling results imply that research priorities are often defined via rather top-down decision making. With digital agro-advisory applications, useful insights into farmers' changing knowledge needs could be generated as by-products of farmers' use of the service itself. Take as an example Google, which as a company knows much about its users' interests and knowledge needs – not by asking them directly, but by analyzing users' queries to its service, an online search engine. Google's 'trendspotting project' has demonstrated the value of these data for predicting emerging consumer trends (such as the 'next big thing' in the beverage market), potentially sparking private research, marketing and investment (Trendspotting Project, 2017).

Similar analyses seem feasible within digital agro-advisory applications. In India, for example, farmers called the 'Lifelines' hotline and recorded questions, which were sent to an online platform as voice messages (Haider Rizvi, 2011). Advisory staff listened to each question, manually attributed keywords, and searched for an adequate answer in an existing database of expert voice messages. With roughly 350 calls per day during peak agricultural season, and each call being tagged with keywords, 'Lifelines' accumulated substantial data about farmers' information needs (Figure 3) (Glendenning & Ficarelli, 2012; Haider Rizvi, 2011). This kind of quantitative analysis of farmers' question topics is also presented for 'Avaaj Otalo' (Patel et al., 2010) and 'Ushauri' (Ortiz-Crespo et al., 2020). The identified information needs

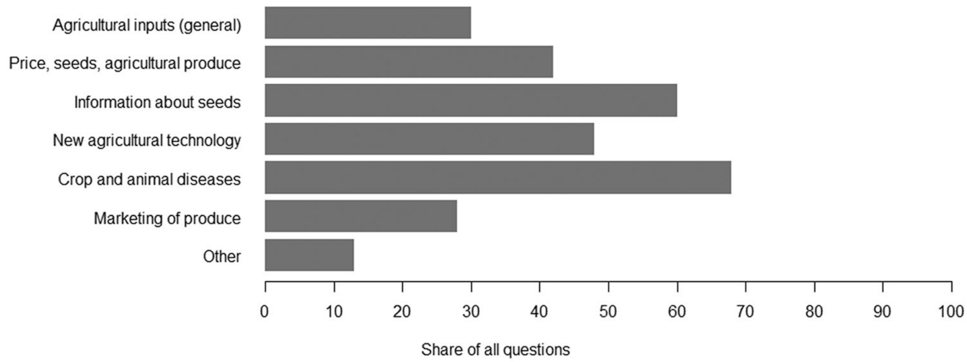

Figure 3. Quantitative overview of topics of farmers' questions submitted to the 'Lifelines' hotline in India. Extension staff listen to each question and assign specific thematic keywords, such as 'disease' or 'marketing'. A more in-depth analysis of the topics farmers are asking about may allow identifying and prioritizing research needs. Figure adapted from Haider Rizvi (2011).

do not necessarily correspond directly to research gaps. Nonetheless, recurrent analysis of the keywords in farmers' questions may highlight emerging topics that are not yet adequately understood by research. In the future, speech recognition software and artificial intelligence could make the tedious process of manually tagging each question with keywords obsolete (Bali et al., 2013). Voice message-based agro-advisory services could then provide inputs to research agenda-setting through (1) identifying the topics farmers are asking questions about, (2) verifying if adequate answers are available in a formal body of knowledge, and (3) determining which information gaps still exist and could be relevant to be addressed by new research.

4.5 Supporting farmer experimentation and observation through agricultural citizen science

In recent years, researchers have emphasized the need for co-creation of innovation, rather than linear knowledge transfer from research via extension to farmers (Kilelu et al., 2013; Klerkx et al., 2012). Extension services can play an important role in engaging farmers in knowledge generation, for example, by supporting on-farm experimentation and systematic observation (Hoffmann et al., 2007; Sumberg et al., 2003). Agricultural researchers, on the other hand, may benefit from farmers' increased participation in agricultural research through rapid replication of trials in diverse environments (Cock et al., 2011). Through the use of digital communication and appropriate methodologies that safeguard data quality, large numbers of individual farmers can make meaningful contributions to agricultural research projects. Such 'citizen science' experiments can speed up the generation of research outputs, such as the development of new crop varieties, at reduced costs compared to on-station trials under researcher supervision (Fadda & van Etten, 2019; Van Etten et al., 2019a). Even without assigning experimental treatments, crowdsourcing simple on-farm observations from farmers can lead to important insights, such as the detection of crop pest and disease outbreaks (Chancellor et al., 2019; Mutembesa et al., 2018).

Setting up citizen science experiments requires careful research design. Crowdsourcing requires splitting a big research task into many experimentation or observation 'micro-tasks' to be carried out by participating farmers. This is followed by the compilation and analysis of large, potentially noisy datasets (Conrad & Hilchey, 2011). Modern ICT can greatly facilitate these efforts. In recent years, specially designed digital platforms have reduced transaction costs for crowdsourcing observations from many users (Minet et al., 2017; Sullivan et al., 2014). One example is the 'ClimMob' online platform (see Box 2), which allows researchers and extension services to design crowdsourced experiments to test agricultural technologies (Van Etten et al., 2017). The spread of mobile phones now makes it possible to collect simple, but accurate on-farm observations from farmers without on-site researcher intervention (Daum et al., 2018; Steinke et al., 2017). In India, Eastern Africa, and Central America, for example, researchers have collaborated with local extension services to carry out variety evaluation trials of annual field crops together with hundreds of farmers (Van Etten et al., 2019a). Getting access to seeds and learning about new crop varieties motivated farmers to participate in citizen science experiments and deliver on-farm observation data (Beza et al., 2017). For researchers, the farmer-generated data had value for assessing the qualities of the varieties (Van Etten et al., 2019b).

Box 2. ClimMob: Crowdsourcing on-farm experimentation with agricultural technology.

The ClimMob software (climmob.net) is a free online tool for designing, managing, and analyzing large-scale agricultural experiments using an on-farm citizen science methodology (van Etten et al., 2017; van Etten et al., 2019b). ClimMob systematically splits a large task of evaluating multiple agricultural technologies in different environments and assigns feasible mini-experiments to individual farmers. The corresponding ClimMob smartphone application is used by researchers and extension agents to collect and compile the farmer-generated data. While communication with farmers is not being automatized, the use of ICT allows rapid integration of the diverse inputs from large numbers of farmers, mediated through many field agents. This allows agricultural research to involve high numbers of farmers with low supervision effort, compared to more researcher-led participatory research methodologies.

4.6 Monitoring and evaluation by analyzing usage data from digital services

Assessing the quality and performance of advisory services is challenging without adequate metrics. Several proxy indicators are in use, such as the number of staff employed, or the budget spent (Anderson & Feder, 2004; Jones & Kondylis, 2018). But these input-related measures are not necessarily informative about the quality of services provided to the recipients of advisory. Digital agro-advisory applications can, however, log users' access and use of the service. This 'usage data' can be used to calculate more meaningful indicators about extension delivery. Examples of such indicators may be the number of farmers reached, how often per season each farmer accessed the service, or how many messages per user were delivered (see Patel et al., 2010).

An illustration of service utilization indicators is provided by the 2019 pilot implementation of the 'Ushauri' hotline in Tanzania (Figure 4; see Ortiz-Crespo et al., 2020). During the 4-week pilot, 86 percent of registered farmers called the 'Ushauri' hotline, making an average of 4.6 calls each. Fifty-six percent of all callers navigated the IVR menu to an end node (listening to an audio message or recording a question). This type of data allows benchmarking against previous versions of the hotline, as well as other services. This way, digital advisory delivery

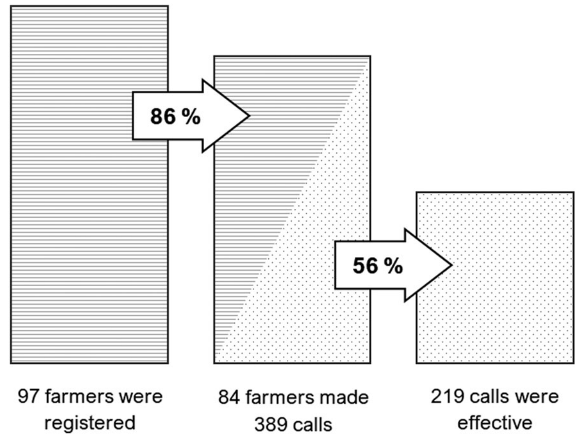

Figure 4. Two conversion rates from a pilot implementation of the 'Ushauri' hotline in Tanzania (Ortiz-Crespo et al., 2020). Eighty-six percent of all registered farmers called the service at least once and listened to the available options in the IVR menu. Fifty-six percent of these callers eventually selected an option, i.e. listened to an audio message or recorded a question.

generates empirical numbers that inform auditable and comparable statements about the overall performance of extension service. Any future modifications of the service or its contents can then be assessed against that baseline, to iteratively improve the quality of extension delivery.

For donors and policy-makers, the performance data allow linking incentives and targets for extension agencies both to their observed absolute reach (e.g. total number of farmers accessing the service, or total number of extension messages delivered) and relative 'conversion rates', such as the number of messages delivered per user, or the share of active users within the population. Using mobile phones to directly elicit farmers' satisfaction with services is possible (see Section 4.8 below). Results can be biased, however, because users who choose not to use the service – for example, by terminating the call after listening to a number of irrelevant information options – do not provide feedback (Jones & Kondylis, 2018). Conversion rates could serve as simple and empirical proxy metrics for the quality and farmer-perceived usefulness of advice.

4.7 Measuring impacts by remote household surveying integrated into advisory applications

It is generally difficult to measure the impacts of agricultural extension on agricultural practice and livelihoods of farming households. This is due to the complexity of possible impact pathways, a frequent lack of reliable household data, and the difficulty and costs of implementing randomized control trials (Knook et al., 2018; Taye, 2013). Although high-quality panel data are available for many countries, they rarely include information on access to agricultural extension services (Carletto et al., 2010). Moreover, such surveys are time-consuming and laborious, and are therefore often only carried out in time intervals of 10 years or more.

Mobile phone-mediated services can address this challenge by integrating the continuous collection of panel data directly with the delivery of advisory contents through digital two-way communication processes. For example, the Ethiopian *Agricultural Transformation Agency*'s 'irrigation help line' uses an IVR interface to request callers' location, gender, and level of irrigation experience. Based on these data, advisory messages are selected (ATA, 2014). In this service, the entry questions are fixed and serve to characterize the user, in order to deliver suitably selected messages. It would just go one step further to use this kind of service for a more complete household characterization. Comprehensive questionnaires could be broken down into small bits of a few questions. These partial questionnaires can be administered progressively each time registered users access the service. The system could collect and store a range of relevant farm and household indicators from many farmers over the course of time, for example, about input use, crop diversity, or farm productivity. An important consideration would be the use of simple, standardized indicators and questionnaires that can be rapidly recalled via digital interfaces (Hammond et al., 2017).

An example of this is the '5Q' approach, originally developed for monitoring farmers' awareness and adoption of climate-smart practices (Jarvis et al., 2015). By periodically asking target farmers five standard questions through automated IVR calls, farmers are grouped along categories such as 'unaware', 'aware', or 'doing'. Over time, this information provides insights into changes in farmers' knowledge and practice (Eitzinger et al., 2019). The enumeration of such mini-questionnaires can be integrated within digital advisory delivery applications. When the information is also used to target different contents to different farmers, as with the irrigation helpline in Ethiopia, farmers are incentivized to provide accurate data.

The collected data about farm activities and performance can eventually be linked with data on the respective farmers' information access (i.e. how often they used the service, which messages they listened to, etc.). This opens opportunities for attributing effects of the service. This does not solve the problems of endogeneity and the lack of a control group, which affect many impact evaluations of extension services. But differential effects of different types of information (e.g. about agronomy, marketing, or value-adding) on different outcome indicators (e.g. yields, income, nutrition) may be traced in a statistically sound way.

4.8 Increasing the accountability of advisory providers by crowdsourcing user evaluations within digital services

The innovation directions discussed in the two previous sections dealt with indirect assessments of advisory performance via usage data from digital applications. Digital solutions also offer more direct opportunities for increasing the accountability of advisory providers towards their clients. Feedback mechanisms, where farmers rate the quality of advice, can be built into digital two-way communication around agricultural advice. Users of the advisory application may actively generate useful data, using IVR touch tones (e.g. 'Give a grade from 1 to 5') or simple speech recognition of standardized rating words (e.g. 'In this message, did you learn anything new? Please say either *yes* or *no*.'). Such crowdsourced, user-generated feedback could then be used to increase the accountability of advisory agencies towards donors and policy-makers in similar ways as the digital service usage data (see Section 4.6).

To achieve useful evaluations, designers need to carefully balance conflicting requirements for standardized and open feedback formats: simplistic ratings and yes/no questions can generate more actionable data than open feedback, but also prevent important contributions on other aspects (Grossman et al., 2018; Jones & Kondylis, 2018). The sense of empowerment that comes with being asked for feedback, however, can also increase farmers' overall demand for advice, leading to increased use of an agro-advisory application (Jones & Kondylis, 2018).

On the supply side, making ratings publicly available can increase the pressure on advisory agencies to deliver satisfactory services. In an experimental study, Pakistani livestock farmers contributed data about the costs and successes of paid artificial insemination services by local veterinarians, and their overall satisfaction with the provider (Hasanain et al., 2017).

Means of these three performance indicators, for multiple artificial insemination providers, were then shared back with farmers via telephone calls. Farmers with access to that information subsequently experienced higher insemination success rates without switching the provider, suggesting that transparent monitoring led to increased efforts among veterinarians. Here, the public availability of user evaluations created an increased pressure to perform.

While the small-scale study by Hasanain et al. (2017) used regular telephone calls, this type of information service could also be fully automated, using IVR, push-calls, or SMS to facilitate two-way information exchange between farmers and the service. An important limitation to the use of crowdsourced evaluations relates to the self-selection of users, since only active users of a digital service also rate its contents. Consequently, these ratings can be used to compare the quality of different contents within the information service, but have limited value for assessing the overall usefulness of the digital application.

5. Beyond digital design: institutional support for the new innovation agenda

Over the last decade, the international development community has produced numerous promising examples of how digital media can serve agricultural advisory. Our review shows that successful digital design must emphasize user-centredness and problem-orientation, giving shape to the new innovation agenda. But taking full advantage of the digital revolution for agricultural extension will likely require more than good digital design. To avoid disillusionment with this new innovation agenda, appropriate institutional support is needed. We suggest seven needs that should be addressed by researchers, designers, policy-makers, and extension service providers.

5.1 Digital solutions should address the diversity of users in a positive way

The widespread uptake of digital innovation has sometimes been limited by differences in the degree of access to mobile phones, related to factors such as gender or wealth status (Deichmann et al., 2016; World Bank, 2016). In addition, differences in technological literacy or the willingness to invest in airtime or data bundles imply that a new digital service may have disparate rates of adoption across different user groups. Some researchers have argued for deliberately targeting tech-savvy 'lead users' (Patel, 2010). However, user diversity can also be factored into the design of new services, by allowing users to adopt different roles and responsibilities. Applications for farmer-to-farmer knowledge sharing (Section 4.3) or agricultural citizen science (Section 4.5), for example, offer opportunities for diversifying users' roles and responsibilities. Not all roles may require access to a personal mobile phone or digital literacy in order to benefit from the service. It is also clear, however, that digital extension applications will not replace classical face-to-face advisory in the foreseeable future, and will, therefore, need to fulfil complementary functions (Matous et al., 2015). The most marginalized farmers, such as illiterate women, are often excluded from agricultural advisory services, but also tend to have limited access to digital media. Deliberately putting these people at the centre of user-centred design processes can lead to solutions that cater to their specific needs and conditions. This includes careful consideration of the information channels and the specific interfaces through which users are able to interact with digital systems. Interfaces do not need to be restricted to mobile phones but can include analogue interfaces to digital services (e.g. scannable paper forms) or physical access points (e.g. a market booth).

5.2 Digital innovation should be treated as a modern farm input

Disappointing rates of early adoption and use must not imply the failure of a digital information service. Rather, farmers' decision-making on whether to use and act upon a new information source follows similar considerations as with new farming technology or inputs. Therefore, the design and introduction of digital services should mind the established characteristics of successful innovations, such as trialability and observability (Rogers, 2003). As with any new agricultural technology, investments into promotional interventions may be needed to increase adoption. This means that beyond creating a well-designed and useful service, achieving adoption may also require classic advertisement campaigns as well as support by local authorities or farmer organizations (Christensen et al., 2019). Governments may consider public subsidies for information services offered by private companies, in analogy to subsidies for seeds, fertilizers, and other agricultural inputs.

5.3 Local capacity is needed for maintaining new services

Many promising services fell out of use when the reality of farmers moved on, while services did not evolve. Future initiatives need to place emphasis on building the local capacities needed to continuously analyse changing user requirements, develop the service, and generate new contents. For extension services, maintaining digital services likely requires investments in staff training (Heeks, 2002). But good design may help, too: procedures for running and updating the information service need to be user-friendly and engaging.

5.4 Innovation needs to go large scale

Many of the innovation directions presented here involve direct network effects. That is, the more farmers use the service, the greater the benefit for each farmer. The opportunities and benefits of farmer-to-farmer knowledge sharing (Section 4.3) or different forms of crowdsourcing (Sections 4.4 and 4.5), for example, increase with growing numbers of active users. Relatively small-scale experimental proof-of-concept studies have now shown the feasibility of the solutions in principle, for example, in terms of user capacities and types of outputs generated. The next step for researchers and policy-makers is to test the viability of the concepts presented here as integral elements of a regional extension system, by integrating elements of digital communication into existing farmer-advisor relationships. Growing experiences with ICT applications as part of routine activities of agricultural advisory services will likely generate further evidence on realistic opportunities and challenges ahead.

5.5 Digital feedback loops need to be set up at extension agencies

Some of the concepts presented here require potentially large datasets to be translated into easily communicable, actionable insights for researchers and policy-makers. Designing and employing appropriate algorithms to make sense of the data accumulating within the applications is key, for example, to defining research needs from farmers' search queries (Section 4.4), or to creating monthly overviews of farmers' service usage for extension supervisors (Section 4.6). Given political support, a small team with knowledge in statistics and programming could be set up within the public extension service. Such a team could create, monitor and adapt the required data loops that link the inputs and outputs of digital advisory service with routines of internal reporting, monitoring and evaluation.

5.6 Extension providers must co-evolve with technology

Tapping the full potential of the use of digital media will require many public extension services to reduce centralized, top-down decision-making in favour of stronger decentralization and diversification of advisory services. Beyond technological innovation, this implies new roles, redistribution of inter-organizational power, and a need for training at all levels (Heeks, 2002; Rivera, 2011). For example, extension agents need to be enabled to act independently and effectively upon information from new ICT applications (Müller et al., 2019). This new role may require substantial revisions to the training curricula of extension staff. Data analysis skills, as well as general digital literacy, are likely to be fundamental to the large-scale deployment of digital agro-advisory services (Eastwood et al., 2019).

But digital media may also improve the performance of extension services through new types of collaboration with civil society and the private sector, including outsourcing of advisory activities. For example, given well-designed mobile agro-advisory applications, the extension system can accommodate 'para-extensionists', who have access to the internet, and whose role consists of operating the applications and mediating advisory contents on behalf of other community members (McCole et al., 2014). Providing moderate training and supervision to such village-based knowledge workers can mitigate a persistent lack of mobile phones or technological literacy among the wider farming population. Eventually, extension staff could focus largely on generating advisory contents, whereas local mediation of information flows and farmer-advisor communication could create job opportunities for tech-savvy rural youth (Fu & Akter, 2016).

5.7 Policy needs to embrace digital development beyond individual projects

Scaling the successes of individual ICT projects to wider, lasting societal benefit requires supportive policy towards an inclusive 'digital society'. This will likely require public investments, to kick-start innovation processes. For example, recognizing the significance of communication and access to information as vital public goods could permit tax breaks or subsidies for mobile phone technology, network infrastructure, airtime, or the development of new information services by the private sector.

As new digital business models become increasingly viable, a growing market for advanced programming and digital design skills is likely to stimulate local capacity for scaling, modifying, and maintaining successful pilot projects. Governments can support the creation of local skills, employment and innovation in the digital sector by facilitating space, infrastructure, and institutional linkages at physical 'tech hubs' and 'incubators' (Kelly & Firestone, 2015). Strategic partnerships between public extension providers and private technology companies may lead to the development of scalable, locally suitable information services. Such public-private collaboration, however, must be embedded in supportive institutional and regulative configurations, which may require an initial coordination effort between a variety of public stakeholders, including from the sectors of agricultural extension, telecommunication, and public finance (Klerkx et al., 2019).

Rather than imposing short project-related funding phases, local governments and international donors could support the emergence of successful digital services through more continued funding of promising initiatives. Increased investment into initial capacity building and iterative design processes, instead of expecting 'quick wins', is likely to enable more flexible and effective adaptation of service prototypes to changing circumstances.

6. Conclusion

Our review presents a new digital innovation agenda for agricultural extension that has been taking shape in recent years. The international development community has generated many novel options to address the communication challenges of agricultural advisory. We suggest our overview can assist designers of new digital agro-advisory applications in selecting appropriate solutions for specific communication problems. Stronger user-centredness and problem-orientation both respond to limitations of previous design approaches. But the use of mobile phones, as channels of two-way communication, creates opportunities to also make advisory services themselves more responsive to both user demand and changing communication challenges. Beyond initial design processes, therefore, tapping the full potential of these technological opportunities will also require changes in current work routines and institutional setups at extension providers. Truly mainstreaming digital innovation will require simultaneous institutional innovation, which may not be easy to implement where extension services are highly politicized, bureaucratic, and/or under-resourced. Yet, creating institutional space for flexible, data-driven, contextualized and decentralized decision-making in agricultural advisory is key to realize the full potential of the emerging digital innovation agenda. Continued local improvization and adaptation, constant modification and maintenance of digital agro-advisory services are indispensable to establish successful digital advisory services in the long run. Therefore, enhancing local digital innovation capacity within advisory organizations will help agricultural extension services in low- and middle-income countries to tap the full potential of the digital revolution.

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References

Aker, J. C. (2011). Dial 'A' for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, *42*(6), 631–647. https://doi.org/10.1111/j.1574-0862.2011.00545.x

Aker, J. C., Ghosh, I., & Burrell, J. (2016). The promise (and pitfalls) of ICT for agriculture initiatives. *Agricultural Economics*, *47*(S1), 35–48. https://doi.org/10.1111/agec.12301

Anderson, J. R., & Feder, G. (2004). Agricultural extension: Good intentions and hard realities. *The World Bank Research Observer*, *19*(1), 41–60. https://doi.org/10.1093/wbro/lkh013

Anderson, J. R., Feder, G., & Ganguly, S. (2006). *The rise and fall of training and visit extension: An Asian mini-drama with an African epilogue*. World Bank Policy Research Working Paper No. 3928.

ATA (Ethiopian Agricultural Transformation Agency). (2014). *2013/14 annual report*. Transforming Agriculture in Ethiopia.

Bali, K., Sitaram, S., Cuendet, S., & Medhi, I. (2013, January 11–12). *A Hindi speech recognizer for an agricultural video search application*. Proceedings of the 3rd ACM symposium on Computing for Development, ACM, Bangalore.

Baumüller, H. (2018). The little we know: An exploratory literature review on the utility of mobile phone-enabled services for smallholder farmers. *Journal of International Development*, *30*(1), 134–154. https://doi.org/10.1002/jid.3314

Bazzano, A. N., Martin, J., Hicks, E., Faughnan, M., & Murphy, L. (2017). Human-centred design in global health: A scoping review of applications and contexts. *PLoS ONE*, *12*(11), e0186744. https://doi.org/10.1371/journal.pone.0186744

Belay, K. (2002). Constraints to agricultural extension work in Ethiopia: The insiders' view. *South African Journal of Agricultural Extension*, *31*, 63–79.

Beza, E., Steinke, J., van Etten, J., Reidsma, P., Fadda, C., Mittra, S., Mathur, P., Kooistra, L., & Rossiter, D. G. (2017). What are the prospects for citizen science in agriculture? Evidence from three continents on motivation and mobile telephone use of resource-poor farmers. *PLoS ONE*, *12*(5), e0175700. https://doi.org/10.1371/journal.pone.0175700

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., Mbabu, A., Spielman, D. J., Horna, D., Benin, S., & Cohen, M. (2009). From best practice to best fit: A framework for designing and analyzing pluralistic agricultural advisory services worldwide. *The Journal of Agricultural Education and Extension*, *15*(4), 341–355. https://doi.org/10.1080/13892240903309595

Blumenstock, J. E., & Eagle, N. (2012). Divided we call: Disparities in access and use of mobile phones in Rwanda. *Information*

Technology and International Development, *8*, 1–16. https://www.itidjournal.org/index.php/itid/article/view/894

Boersma, A. (2017). The future of KM? Design thinking! So here are 5 elements to 'ECHO'. *Knowledge Management for Development Journal*, *13*, 25–30. https://www.km4djournal.org/index.php/km4dj/article/view/293

Carletto, G., Beegle, K., Himelein, M., Kilic, T., Murray, S., Oseni, M., Scott, K., & Steele, D. (2010, May 24–25). *Improving the availability, quality and policy-relevance of agricultural data: The living standards measurement study – integrated surveys on agriculture*. Proceedings of the Third Wye City Group Global Conference on Agricultural and Rural Household Statistics, Washington, DC.

Carmona, M., Sautua, F., Perelman, S., Gally, M., & Reis, E. M. (2015). Development and validation of a fungicide scoring system for management of late season soybean diseases in Argentina. *Crop Protection*, *70*, 83–91. https://doi.org/10.1016/j.cropro.2015.01.019

Carmona, M. A., Sautua, F. J., Pérez-Hernández, O., & Mandolesi, J. I. (2018). AgroDecisor EFC: First Android™ app decision support tool for timing fungicide applications for management of late-season soybean diseases. *Computers and Electronics in Agriculture*, *144*, 310–313. https://doi.org/10.1016/j.compag.2017.11.028

Chancellor, T. C. B., Priebe, J. S. H., & Mkenda, P. A. (2019). Crowdsourcing field observations from smallholder farmers in Tanzania using interactive voice response. *Outlooks on Pest Management*, *30*(3), 104–110. https://doi.org/10.1564/v30_jun_02

Christensen, L. R., Ahsan, H., Rashid, M., & Das, B. K. (2019, January 4–7). *Are you magicians? The collaborative work of an agricultural information service*. Proceedings of the 10th international conference on Information and Communication Technologies and Development (ICTD19), Ahmedabad, India.

Cock, J., Oberthür, T., Isaacs, C., Roman, P., Palma, A., Carbonell, J., Victoria, J., Watts, G., Amaya, A., Collet, L., Lema, G., & Anderson, E. (2011). Crop management based on field observations: Case studies in sugarcane and coffee. *Agricultural Systems*, *104*(9), 755–769. https://doi.org/10.1016/j.agsy.2011.07.001

Conrad, C. C., & Hilchey, K. G. (2011). A review of citizen science and community-based environmental monitoring: Issues and opportunities. *Environmental Monitoring and Assessment*, *176*(1–4), 273–291. https://doi.org/10.1007/s10661-010-1582-5

Courtois, P., & Subervie, J. (2015). Farmer bargaining power and market information services. *American Journal of Agricultural Economics*, *97*(3), 953–977. https://doi.org/10.1093/ajae/aau051

Daum, T., Buchwald, H., Gerlicher, A., & Birner, R. (2018). Smartphone apps as a new method to collect data on smallholder farming systems in the digital age: A case study from Zambia. *Computers and Electronics in Agriculture*, *153*, 144–150. https://doi.org/10.1016/j.compag.2018.08.017

Davis, K. (2008). Extension in Sub-Saharan Africa: Overview and assessment of past and current models, and future prospects. *Journal of International Agricultural Extension and Education*, *15*, 15–28.

Deichmann, U., Goyal, A., & Mishra, D. (2016). Will digital technologies transform agriculture in developing countries? *Agricultural Economics*, *47*(S1), 21–33. https://doi.org/10.1111/agec.12300

Dodson, L., Sterling, S. R., & Bennett, J. K. (2013). Considering failure: Eight years of ITID research. *Information Technology and International Development*, *9*, 19–34. http://52.37.125.211/index.php/itid/article/view/1050

Duncombe, R. (2015). Mobile phones for agricultural and rural development: A literature review and suggestions for future research. *European Journal of Development Research*, *28*(2), 1–23. https://doi.org/10.1057/ejdr.2014.60

Eastwood, C., Ayre, M., Nettle, R., & Dela Rue, B. (2019). Making sense in the cloud: Farm advisory services in a smart farming future. *NJAS – Wageningen Journal of Life Sciences*, *90-91*, 100298. https://doi.org/10.1016/j.njas.2019.04.004

Eitzinger, A., Cock, J., Atzmanstorfer, K., Binder, C. R., Läderach, P., Bonilla-Findji, O., Bartling, M., Mwongera, C., Zurita, L., &Jarvis, A. (2019). Geofarmer: A monitoring and feedback system for agricultural development projects. *Computers and Electronics in Agriculture*, *158*, 109–121. https://doi.org/10.1016/j.compag.2019.01.049

Fabregas, R., Kremen, M., & Schilbach, F. (2019). Realizing the potential of digital development: The case of agricultural advice. *Science*, *366*(6471), eaay3038. https://doi.org/10.1126/science.aay3038

Fadda, C., & van Etten, J. (2019). Generating farm-validated variety recommendations for climate adaptation. In T. Rosenstock, E. Girvetz, & A. Nowak (Eds.), *The climate-smart Agriculture Papers* (pp. 127–138). Springer.

Faure, G., Desjeux, Y., & Gasselin, P. (2012). New challenges in agricultural advisory services from a research perspective: A literature review, synthesis and research agenda. *The Journal of Agricultural Education and Extension*, *18*(5), 461–492. https://doi.org/10.1080/1389224X.2012.707063

Feder, G., Anderson, J. R., Birner, R., & Deininger, K. (2010). *Promises and realities of community-based agricultural extension*. IFPRI Discussion Paper No 959.

Fu, X., & Akter, S. (2016). The impact of mobile phone technology on agricultural extension services delivery: Evidence from India. *The Journal of Development Studies*, *52*(11), 1561–1576. https://doi.org/10.1080/00220388.2016.1146700

Glendenning, C. J., & Ficarelli, P. (2012). *The relevance of content in ICT initiatives in Indian agriculture*. IFPRI Discussion paper No 1180.

Grossman, G., Platas, M. R., & Rodden, J. (2018). Crowdsourcing accountability: ICT for service delivery. *World Development*, *112*, 74–87. https://doi.org/10.1016/j.worlddev.2018.07.001

GSMA. (2017). *State of the industry report on mobile money*.

Gulliksen, J., Göransson, B., Boivie, I., Blomkvist, S., Persson, J., & Cajander, A. (2003). Key principles for user-centred systems design. *Behavior & Information Technology*, *22*(6), 397–409. https://doi.org/10.1080/01449290310001624329

Haider Rizvi, S. M. (2011). Lifelines: Livelihood solutions through mobile technology in India. In D. J. Grimshaw & S. Kala (Eds.), *Strengthening rural livelihoods: The impact of information and communication technologies in Asia* (pp. 53–70). Practical Action Publishing and International Development Research Centre.

Hammond, J., Fraval, S., van Etten, J., Gabriel, J., Mercado, L., Pagella, T., Frelat, R., Lannerstad, M., Douxchamps, S., Teufel, N., Valbuena, D., & van Wijk, M. T. (2017). The rural household multi-indicator survey (RHoMIS) for rapid characterisation of households to inform climate smart agriculture interventions: Description and applications in East Africa and Central

America. *Agricultural Systems*, *151*, 225–233. https://doi.org/10.1016/j.agsy.2016.05.003

Hampson, K., Sones, D., & Watiti, J. (2018). *Scaling-up improved legume technologies in Tanzania (SILT): Final Technical Report*. Farm Radio International, CABI, and Africa Fertilizer & Agribusiness Partnership.

Hasanain, A., Khan, Y., & Rezaee, A. (2017). No bulls: Crowdsourcing away asymmetric information in the market for artificial insemination in Pakistan [Unpublished manuscript]. https://armanrezaee.github.io/pdfs/livestock_3sept2019.pdf, last accessed March 9, 2020.

Hassenzahl, M., & Tractinsky, N. (2006). User experience – a research agenda. *Behavior & Information Technology*, *25*(2), 91–97. https://doi.org/10.1080/01449290500330331

Heeks, R. (2002). Information systems and developing countries: Failure, success, and local improvisations. *The Information Society*, *18*(2), 101–112. https://doi.org/10.1080/01972240290075039

Hoffmann, V., Probst, K., & Christinck, A. (2007). Farmers and researchers: How can collaborative advantages be created in participatory research and technology development? *Agriculture and Human Values*, *24*(3), 355–368. https://doi.org/10.1007/s10460-007-9072-2

IDEO.org. (2015). *The field guide to human-centered design*. IDEO.org.

Jarvis, A., Eitzinger, A., Koningstein, M. J., Benjamin, T., Howland, F. C., Andrieu, N. V., Twyman, J., & Corner-Dolloff, C. (2015). *Less is More: The 5Q Approach*. CIAT.

Jones, M., & Kondylis, F. (2018). Does feedback matter? Evidence from agricultural services. *Journal of Development Economics*, *131*, 28–41. https://doi.org/10.1016/j.jdeveco.2017.10.013

Kelly, T., & Firestone, R. (2015). *How tech hubs are helping to drive economic growth in Africa*. Background paper to the World Development Report 2016: Digital Dividends.

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

Klerkx, L., Jakku, E., & Labarthe, P. (2019). A review of social science on digital agriculture, smart farming and agriculture 4.0: New contributions and a future research agenda. *NJAS – Wageningen Journal of Life Sciences*, *90–91*, 100315. https://doi.org/10.1016/j.njas.2019.100315

Klerkx, L., Schut, M., Leeuwis, C., & Kilelu, C. (2012). Advances in knowledge brokering in the agricultural sector: Towards innovation system facilitation. *IDS Bulletin*, *43*(5), 53–60. https://doi.org/10.1111/j.1759-5436.2012.00363.x

Knook, J., Eory, V., Brander, M., & Moran, D. (2018). Evaluation of farmer participatory extension programmes. *The Journal of Agricultural Education and Extension*, *24*(4), 309–325. https://doi.org/10.1080/1389224X.2018.1466717

Krishnan, P., & Patnam, M. (2014). Neighbors and extension agents in Ethiopia: Who matters more for technology adoption? *American Journal of Agricultural Economics*, *96*(1), 308–327. https://doi.org/10.1093/ajae/aat017

Masiero, S. (2016). The origins of failure: Seeking the causes of design–reality gaps. *Information Technology for Development*, *22*(3), 487–502. https://doi.org/10.1080/02681102.2016.1143346

Matous, P., Todo, Y., & Pratiwi, A. (2015). The role of motorized transport and mobile phones in the diffusion of agricultural information in Tanggamus Regency, Indonesia. *Transportation*, *42*(5), 771–790. https://doi.org/10.1007/s11116-015-9646-6

McCole, D., Culbertson, M. J., Suvedi, M., & McNamara, P. E. (2014). Addressing the challenges of extension and advisory services in Uganda: The Grameen Foundation's community knowledge worker program. *Journal of International Agricultural and Extension Education*, *21*(1), 6–18. https://doi.org/10.5191/jiaee.2014.20101

Minet, J., Curnel, Y., Gobin, A., Goffart, J. P., Mélard, F., Tychon, B., Wellens, J., & Defourny, P. (2017). Crowdsourcing for agricultural applications: A review of uses and opportunities for a farmsourcing approach. *Computers and Electronics in Agriculture*, *142*, 126–138. https://doi.org/10.1016/j.compag.2017.08.026

Müller, A., Mora, V., Rojas, E., Díaz, J., Fuentes, O., Giron, E., Gaytan, A., & van Etten, J. (2019). Emergency drills for agricultural drought response: A case study in Guatemala. *Disasters*, *43*(2), 410–430. https://doi.org/10.1111/disa.12316

Mutembesa, D., Omongo, C., & Mwebaze, E. (2018, July 5–8). *Crowdsourcing real-time viral disease and pest information: A case of nation-wide cassava disease surveillance in a developing country*. Proceedings of the Sixth AAAI conference on Human Computation and Crowdsourcing (HCOMP 2018), Zurich.

Mwombe, S. O. L., Mugivane, F. I., Adolwa, I. S., & Nderitu, H. (2014). Evaluation of information and communication technology utilization by small holder banana farmers in Gatanga District, Kenya. *The Journal of Agricultural Education and Extension*, *20*(2), 247–261. https://doi.org/10.1080/1389224X.2013.788454

Nakasone, E., & Torero, M. (2016). A text message away: ICTs as a tool to improve food security. *Agricultural Economics*, *47*(S1), 49–59. https://doi.org/10.1111/agec.12314

Nakasone, E., Torero, M., & Minten, B. (2014). The power of information: The ICT revolution in agricultural development. *Annual Review of Resource Economics*, *6*(1), 533–550. https://doi.org/10.1146/annurev-resource-100913-012714

Neef, A., & Neubert, D. (2011). Stakeholder participation in agricultural research projects: A conceptual framework for reflection and decision-making. *Agriculture and Human Values*, *28*(2), 179–194. https://doi.org/10.1007/s10460-010-9272-z

Norman, D. (1988). *The psychology of everyday things*. Basic Books.

Ortiz-Crespo, B., Steinke, J., Quirós, C. F., Daudi, H., Mgimiloko, M. G., & van Etten, J. (2020). User-centered design of a digital advisory service: enhancing public agricultural extension for sustainable intensification in Tanzania. *International Journal of Agricultural Sustainability*, (Special Issue: Sustainable Agricultural Intensification), 1–17. https://doi.org/10.1080/14735903.2020.1720474

Patel, N. (2010). Not your average farmer: Designing for lead users in ICT4D research. *Interactions*, *17*(5), 50–52. https://doi.org/10.1145/1836216.1836229

Patel, N., Chittamuru, D., Jain, A., Dave, P., & Parikh, T. S. (2010, April 10–15). *Avaaj Otalo – A field study of an interactive voice forum for small farmers in rural India*. Proceedings of the SIGCHI conference on Human Factors in Computing Systems, Atlanta, GA.

Patel, N., Savani, K., Klemmer, S. R., & Parikh, T. S. (2013). Power to the peers: Authority of source effects for a voice-based agricultural information service in rural India. *Information Technology and International Development*, *9*, 81–93.

Patnaik, S., Brunskill, E., & Thies, W. (2009, April 17–19). *Evaluating the accuracy of data collection on mobile phones: A study of forms, SMS, and voice*. Proceedings of the international conference on Information and Communication Technologies and Development (ICTD), Doha, Qatar.

Qiang, C. Z., Kuek, S. C., Dymond, A., & Esselaar, S. (2012). *Mobile applications for agriculture and rural development* [Report No. 96226-GLP], ICT Sector Unit, World Bank.

Rivera, W. M. (2011). Public sector agricultural extension system reform and the challenges ahead. *The Journal of Agricultural Education and Extension*, *17*(2), 165–180. https://doi.org/10.1080/1389224X.2011.544457

Rogers, E. M. (2003). *The diffusion of innovations*. The Free Press.

Rosenstock, T. S., Lamanna, C., Chesterman, S., Hammond, J., Kadiyala, S., Luedeling, E., Shepherd, K., DeRenzi, B., & van Wijk, M. T. (2017). When less is more: Innovations for tracking progress toward global targets. *Current Opinion in Environmental Sustainability*, *26–27*, 54–61. https://doi.org/10.1016/j.cosust.2017.02.010

Schut, M., Klerkx, L., Sartas, M., Lamers, D., McCampbell, M., Ogbonna, I., Kaushik, P., Atta-Krah, K., & Leeuwis, C. (2016). Innovation platforms: Experiences with their institutional embedding in agricultural research for development. *Experimental Agriculture*, *52*(4), 537–561. https://doi.org/10.1017/S001447971500023X

Snyder, C. (2003). *Paper prototyping: The fast and easy way to design and refine user interfaces*. Morgan Kaufmann.

Steinke, J., Achieng, J. O., Hammond, J., Kebede, S. S., Mengistu, D. K., Mgimiloko, M. G., Mohammed, J. N., Musyoka, J., Sieber, S., van de Gevel, J., van Wijk, M., & van Etten, J. (2019). Household-specific targeting of agricultural advice via mobile phones: Feasibility of a minimum data approach for smallholder context. *Computers and Electronics in Agriculture*, *162*, 991–1000. https://doi.org/10.1016/j.compag.2019.05.026

Steinke, J., van Etten, J., & Mejía Zelan, P. (2017). The accuracy of farmer-generated data in an agricultural citizen science methodology. *Agronomy for Sustainable Development*, *37*(4), 32. https://doi.org/10.1007/s13593-017-0441-y

Sulaiman, R., Hall, A., Kalaivani, N. J., & Dorai, K. (2012). Necessary, but not sufficient: Critiquing the role of information and communication technology in putting knowledge into use. *The Journal of Agricultural Education and Extension*, *18*(4), 331–346. https://doi.org/10.1080/1389224X.2012.691782

Sullivan, B. L., Aycrigg, J. L., Barry, J. H., Bonney, R. E., Bruns, N., Cooper, C. B., Damoulas, T., Dhondt, A. A., Dietterich, T., Farnsworth, A., Fink, D., Fitzpatrick, J. W., Fredericks, T., Gerbracht, J., Gomes, C., Hochachka, W. M., Iliff, M. J., Lagoze, C., La Sorte, F. A., … Kelling, S. (2014). The eBird enterprise: An integrated approach to development and application of citizen science. *Biological Conservation*, *169*, 31–40. https://doi.org/10.1016/j.biocon.2013.11.003

Šūmane, S., Kunda, I., Knickel, K., Strauss, A., Tisenkopfs, T., Rios, I. d. I., Rivera, M., Chebach, T., & Ashkenazy, A. (2018). Local and farmers' knowledge matters! How integrating informal and formal knowledge enhances sustainable and resilient agriculture. *Journal of Rural Studies*, *59*, 232–241. https://doi.org/10.1016/j.jrurstud.2017.01.020

Sumberg, J., Okali, C., & Reece, D. (2003). Agricultural research in the face of diversity, local knowledge and the participation imperative: Theoretical considerations. *Agricultural Systems*, *76*(2), 739–753. https://doi.org/10.1016/S0308-521X(02)00153-1

Taye, H. (2013). Evaluating the impact of agricultural extension programmes in sub-Saharan Africa: Challenges and prospects. *African Evaluation Journal*, *1*(1), 1–9. https://doi.org/10.4102/aej.v1i1.19

Taylor, M., & Bhasme, S. (2018). Model farmers, extension networks and the politics of agricultural knowledge transfer. *Journal of Rural Studies*, *64*, 1–10. https://doi.org/10.1016/j.jrurstud.2018.09.015

Tongia, R., & Subrahmanian, E. (2006). *Information and communications technology for development (ICT4D) – A design challenge?* Department of Engineering and Public Policy, Paper No. 119.

Trendspotting Project. (2017). *Beverage trends report 2017*.

Van Etten, J., Beza, E., Calderer, L., van Duijvendijk, K., Fadda, C., Fantahun, B., Kidane, Y. G., Van de Gevel, J., Gupta, A., Mengistu, D. K., Kiambi, D., Mathur, P. N., Mercado, L., Mittra, S., Mollel, M. J., Rosas, J. C., Steinke, J., Suchini, J. G., & Zimmerer, K. S. (2019a). First experiences with a novel farmer citizen science approach: Crowdsourcing participatory variety selection through on-farm triadic comparisons of technologies (tricot). *Experimental Agriculture*, *55*(S1), 275–296. https://doi.org/10.1017/S0014479716000739

Van Etten, J., de Sousa, K., Aguilar, A., Barrios, M., Coto, A., Dell'Acqua, M., Fadda, C., Gebrehawaryat, Y., van de Gevel, J., Gupta, A., Kiros, A. Y., Madriz, B., Mathur, P., Mengistu, D. K., Mercado, L., Nurhisen Mohammed, J., Paliwal, A., Pè, M. E., Quirós, C. F., … Steinke, J. (2019b). Crop variety management for climate adaptation supported by citizen science. *Proceedings of the National Academy of Sciences*, *116*(10), 4194–4199. https://doi.org/10.1073/pnas.1813720116

Van Etten, J., Quirós, C., Madriz, B., & de Sousa, K. (2017). *Climmob, digital platform to support triadic comparisons of technologies (tricot)*. CGIAR Gender & Breeding Initiative, Nairobi, Kenya.

World Bank. (2016). *World development report 2016: Digital dividends*. World Bank.

Wyche, S., & Steinfield, C. (2016). Why don't farmers use cell phones to access market prices? Technology affordances and barriers to market information services adoption in rural Kenya. *Information Technology for Development*, *22*(2), 320–333. https://doi.org/10.1080/02681102.2015.1048184