Information and Communication Technologies (ICTs): The Potential for Enhancing the Dissemination of Agricultural Information and Services to Smallholder Farmers in Sub-Saharan Africa

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Abstract

The transformation of smallholder farming is poised to be one of the key drivers of achieving the dual objectives of food security and poverty reduction in Sub-Saharan Africa (SSA). Smallholder farmers account for between 60-80% of the food produced in the region but face many challenges that impede their productivity. Such challenges include a lack of timely access to appropriate agricultural information and services, which results in poor decision-making, particularly in addressing challenges and responding effectively to opportunities. In that context, the effective use of Information and Communication Technologies (ICTs) in improving accessibility to appropriate agricultural information and services presents substantial prospects for transforming the productivity and livelihoods of the farmers. Currently, the region experiences massive penetration and propagation of mobile and web-based applications. However, there is a dearth of compelling, comprehensive reviews evaluating their importance in enhancing agricultural information and services dissemination to smallholder farmers. Therefore, the current review explores the potential of enhancing agricultural information and services dissemination to smallholder farmers through ICTs and highlights gaps in their development and deployment in SSA. Five existing mobile applications used to disseminate agricultural information and services to smallholder farmers were identified, and their advantages, limitations, and opportunities were discussed. These were Esoko, iCow, Community Knowledge Workers, WeFarm and DigiFarm. The development and deployment of user-driven mobile applications that provide curated skill-sharing platforms, encourage farmers to give feedback to extension systems in real-time and promote the participation of women and youth in agriculture are recommended.

Keywords: information and communication technologies; mobile application; smallholder farmer; agricultural information dissemination; sub-Saharan Africa

Introduction

The dynamic revolution and widespread of Information and Communication Technologies (ICTs) such as web-based and mobile applications continue to generate new prospects for transforming smallholder farming systems in SSA (Emeana et al., 2020; Hopestone, 2014; Tsan et al., 2019). According to Verdier-chouchane and Karagueuzian (2016), ICT is "…...a heterogeneous set of goods and services used to produce, process, distribute and transform information". It comprises "…. any device, tool, or application that permits the exchange or collection of data through interaction or transmission" (World Bank, 2017). Within agricultural industries particularly farming systems, ICTs are perceived as vectors of grassroots innovation, transformation, and socio-economic growth (Drafor, 2016; Sector Network Rural Development Africa (SNRD), 2016). Thus, their universal revolution has demonstrably improved how farmers work, access information, connect and be productive (Food and Agriculture Organisation (FAO), 2018; Isenberg, 2019). Broadly, web-based and mobile applications can be used to empower the disadvantaged and strategic groups such as youths and women in rural agriculture by re-engaging them and improving their access to information and support resources (Henze & Ulrichs, 2016; International Telecommunication Union (ITU), 2020; Verdier-chouchane & Karagueuzian, 2016).

Across the SSA region, agriculture is vital in alleviating poverty, and driving economic growth and social development (Hopestone, 2014). It constitutes the highest fraction of the employed population (about 65%) (Alliance for Green Revolution in Africa (AGRA), 2015). In the SSA region, smallholder farming remains the predominant form of agriculture representing nearly 80% of its total farmers (Verdier-chouchane and Karagueuzian, 2016) who produce close to 80% of the food (Lowder et al., 2014; Ogbeide and Ele, 2015; Tsan et al., 2019). However, the region continues to be faced with the highest food insecurity risk compared to other regions with its population being projected to increase 2.5-fold by 2050 (Tsan et al., 2019). Considering these predictions and the potential of smallholders in leveraging agrarian change and alleviating rural poverty and hunger, improving the viability of these small and marginal farms becomes critical (Fan and Rue, 2020; Kamara et al., 2019).

For a long time, the substantial transformation of smallholder farming systems in SSA has been difficult to achieve. Thus, most smallholders are not as productive and profitable as they could potentially be and their production systems are still in subsistence and semi-subsistence farming (FAO, 2017; Henze and Ulrichs, 2016; Ogbeide and Ele, 2015). The transformation of smallholder farming has been hampered by many factors including lack of markets and unfair market conditions, poor access to advanced technologies, frail infrastructure, gender imbalance, and political instability (Fan and Rue, 2020; World Bank, 2017; Zyl et al., 2014). Also, climate variability and the prevailing drought conditions have grossly affected the viability of smallholder farming systems in the region (Anadozie et al., 2021; Chingala et al., 2017; Rust and Rust, 2013). However, these challenges are compounded by a set of limitations associated with poor access to relevant and timely agricultural information and services (Mapiye et al., 2019; Van Schalkwyk et al., 2017). This is informed by the compelling philosophies that farmers need more localised information and services because agriculture is increasingly becoming complex and knowledge-intensive (Ali, 2012; Batchelor et al., 2014; SNRD, 2016). Literature has many studies (Amer et al., 2018; Consolata, 2017; Drafor, 2016; Mapiye et al., 2019; SNRD, 2016) describing how limited access to information and services constrain farmers' decision-making process and increase their vulnerabilities to climate change risks. Mbanda-Obura, Tabu, Amudavi, and Obura (2017) and Anadozie et al. (2021) suggest that besides instigating diverging perceptions and sub-optimal choices by farmers, lack of appropriate information weakens their ability to control their everyday challenges and optimise the use of available resources. According to Ochieng, Juma, and Jakinda 2014), information asymmetry hampers access to markets, adoption of modern technologies, and farm productivity among smallholder farmers. One of the ways to improve access to agricultural information and services in smallholder farming systems is the adoption and use of ICT-based innovations especially mobile and web-based strategies (Consolata, 2017; Ogbeide & Ele, 2015; Emeana et al., 2020). The use of ICT-based technologies presents opportunities for the creation, dissemination, and sharing of customised information among farmers and across the farmers-extension-research nexus (FAO, 2017; Mapiye et al., 2019). Mobile technologies can boost peer-to-peer interactivity, and hence initiate the creation of immersive and user-driven participatory solutions (Aker and Mbiti, 2010; FAO, 2018). Past studies have so far estimated some positive contributions from using mobile phone technologies to support smallholder farmers in Africa (Emeana et al., 2020; Hopestone, 2014; Nakasone et al., 2013). In this context, it is important to continuously invest and innovate towards the development and deployment of mobile technologies to support smallholder transformation.

A report by FAO (2017) argued that existing research on SSA's agricultural digital information and services delivery system is still fragmented and experimental. They are very few if any reviews critiquing existing mobile and web-based applications deployed for use by smallholder farmers in SSA. This paper, therefore, sets out to explore the potential of mobile and web-based technologies and gaps in their deployment in SSA in supporting the dissemination of agricultural information and services towards smallholder farmers. In achieving this aim, the review seeks to answer some critical questions using relevant case studies. The initial question is on mobile and web-based technologies' relevance and general impact on smallholder agriculture and rural development in the SSA region. The second question explores trends and current statistics on the revolution of mobile phones, network and internet availability, and accessibility by smallholders in the region. This will be followed by a question on factors constraining the adoption of mobile and web-based technologies by smallholders in the region. Also, the review addresses the central questions of what mobile and web-based technologies are available to improve the provision of information and extension services to smallholder farmers and the issues surrounding their scalability and areas of origin. Answering this question provides a critique of case studies of ICT-based initiatives currently being commercially used to support smallholder farmers. The last question of the paper explores the gaps and general limitations of the existing apps while providing a prospective analysis and concise recommendations for researchers and future technology developers.

Review Methodology

The review included mainly research publications from accredited journals and reports from regional and world institutions which were published between the years 2007 and 2021. The search was conducted in 5-year periods (2006–2010; 2011–2015; 2016–2021). The proportions of articles obtained for each period were 4%, 34%, and 62%, respectively with the total number of articles used being 94. Major electronic databases such as Google Scholar, Science Direct, AGRICOLA, SciELO, and SpringerLink were systematically searched to identify all eligible articles. The first search was conducted in March 2019. More searches were then repeated in August 2020 and March 2021. For the initial search, Boolean search strings ‘Mobile phone applications’ AND ‘ICTs revolution’ AND ‘information dissemination’ AND ‘smallholder farmers’ AND ‘Sub-Saharan Africa’ were used. Thereafter, the strings ‘mobile phone penetration’ AND ‘internet connectivity’ AND ‘mobile network accessibility’ AND ‘constraints’ AND ‘smallholder farmers’ AND ‘Sub-Saharan Africa’ were also used.

The inclusion criteria for the five mobile applications (Esoko, iCow, Community Knowledge Worker, WeFarm, and DigiFarm) selected for this review was based on their operational scale in various countries, commercial potential and use in the dissemination of information and services in SSA. The search was then narrowed to focus on these selected tools. For example, a combination of the terms "Esoko", "application", and "Africa" was used to search for articles about the Esoko mobile application. Articles providing detailed information on the establishment aims, specific uses (e.g., provision of information and services), replicability and scalability and limitations of the technology were retrieved.

Full-text articles were accessed for free through links provided by the search engines visited and where the article was not found, websites such as ResearchGate which gives an option to request full texts directly from authors, were utilized. The research articles and reports that might have been dropped from the first search were retrieved through the Google search engine. Also, reference lists of included articles were checked, and this was followed by performing a citation tracking in which all the articles that cite each of the included articles were tracked. In some cases, the published information regarding the five innovations was not consistent, so the review presents the available information for each innovation.

The relevance of ICTs to Smallholder Agriculture and Rural Development in SSA

Rural Development is a dynamic concept that suggests the positive economic, social and human transformation of a group of people from a previous situation (Wiggins et al., 2018). It is not cultivated from a single activity but stems from various interventions all contributing towards rural growth. Smallholder farming is one of the essential activities not only driving rural development but also natural resource conservation (Kamara et al., 2019) and igniting growth in the mainstream parts such as the non-farming economy (Wiggins et al., 2018). This could imply that the concepts of 'agrarian change' and 'rural development' are co-dependent. It is, therefore, imperative to constantly promote agricultural development especially through the transformation of smallholder farming systems.

Agricultural extension remains the mainstay of smallholder agricultural systems and hence rural development in SSA (Danso-Abbeam et al., 2018; Raidimi and Kabiti, 2019). It is responsible for transferring agricultural information to farmers as well as improving their capacity building, productivity, and well-being (Akpalu, 2013; Deichmann et al., 2016;). Within smallholder production systems, the public extension is the key source of information and advisory services for farmers (Ali, 2012; Mapiye et al., 2019; Raidimi and Kabiti, 2019). However, given its linear and top-down approach and many limitations such as lack of support resources and high farmer-to-extension ratio, the public extension has failed to effectively support the smallholder sector (Ali, 2012; Consolata, 2017; FAO, 2017). The harnessing of strategies to reform and improve the efficiency of extension systems in delivering information and services to smallholders is, therefore, critical.

Clinically, in the past few decades, discourses on the potential strategies which can be used to improve the efficiency of extension in delivering information to smallholders point to the adoption and utilisation of ICTs such as mobile and web-based technologies (Consolata, 2017; Hopestone, 2014; Quandt et al., 2020). Various ICT-based initiatives have, therefore, been developed and are widely distributed across the SSA region. According to Tsan et al. (2019), about 43 of the 49 countries in SSA have some form of digital for agriculture-based solutions with more than 50 percent of the innovations being headquartered in Kenya. Currently, digital for agriculture solutions have registered more than 33 million smallholder farmers and pastoralists across Africa. Zyl et al. (2014), World Bank (2017), and FAO (2017) state that the increasing ubiquity of these technologies and broadband connectivity is helping to reduce poverty by bringing high-end services closer to the rural farmers. Infusing extension with digital technologies can, therefore, promote and hasten back-to-back interactions (feedbacking) between farmers and extension. Also, given that smallholder farmers are invariably innovators who actively engage in skills and innovations sharing (Drafor, 2016; Mapiye et al., 2019), the evolution of ICTs presents new and efficient channels for strengthening this, especially among the remotely located rural farmers (Daum et al., 2018). Furthermore, these new interventions allow for the capturing, organizing, and preserving of traditional or local knowledge shared by farmers (World Bank, 2017).

Apart from improving the extension service delivery, the emerging ICTs can promote the development of initiatives bringing financial services such as mobile money, to smallholder farmers in SSA(Emeana et al., 2020; Kikulwe et al., 2014; Verdier-chouchane and Karagueuzian, 2016). Financial service initiatives such as Agrinet from Uganda, M-Pesa in Kenya (World Bank, 2017), EcoCash in Zimbabwe (Ifeoma and Hove Tawanda, 2015), and eWallet in Nigeria (Adebo, 2014) are critical innovations promoting the participation of smallholder farmers in agricultural value chains through access to mobile banking services. These services are valuable opportunities for improving gender equality (FAO, 2017) and youth engagement in agriculture (AGRA, 2015) and have a positive net impact on household income (Kikulwe et al., 2014). In a study by Suri and Jack (2016) and Kikulwe et al. (2014) in Kenya, the use of mobile money services reduced extreme poverty in female-headed households by 22% and positively impacted household income of smallholder farmers respectively. Thus, improved access to finance by women farmers can increase agricultural productivity and reduce poverty levels in the region (FAO, 2018). This is because women constitute the majority of smallholder farmers (Isaya et al., 2018; Tsan et al., 2019) and perform more than 60% of all agricultural activities in the smallholder sector (Zyl et al., 2014).

Digitalisation is strengthening the participation, interactions, and market linkage among smallholder producers leading to improved productivity and profitability (Hopestone, 2014; Krone et al., 2016; Qiang et al., 2012). Thus, many empirical studies have shown that the innovations can reduce the time and costs of traveling by farmers, facilitate their social learning and generate employment opportunities for them and their families (Consolata, 2017; ITU, 2014; Quandt et al., 2020). In a study conducted in four rural farming communities in Tanzania by Quandt et al. (2020) the use of ICTs like mobile phones was reported by 60% of the respondents to have helped them increase profits from farming. Farmers were using phones to locate cheaper and nearer fertiliser sellers and recruit cheaper transport service providers, saving them both on time and money. Previously, Aker and Mbiti (2010), found that the use of mobile phone-enabled technologies reduced search costs of agricultural price information by 50 percent within Niger's rural farming sector. Besides improving access to market information by smallholders, the use of ICT is perceived to help in disrupting monopolistic market activities (Aker and Mbiti, 2010). This eventually promotes the growth of small formal markets which largely support smallholders. Despite fast technological advancement and the supposedly discussed new opportunities for developing smallholder agriculture, the interventions largely depend on the accessibility to mobile phones, the internet, and mobile connectivity especially by the rural poor.

Mobile Phone Subscriptions and Network Accessibility in SSA

For the past two decades, people in SSA, particularly the rural poor are increasingly more interconnected and this is largely driven by access to mobile phones (Deichmann et al., 2016; Kikulwe et al., 2014). About 81% (995 million) of Africans had mobile connections in 2018 (Germany Corporation for International Cooperation-GmbH (GIZ), 2018; Kemp, 2019). According to Global Systems for Mobile Communications Association (GSMA) (2020), the mobile-cellular market for SSA reached 477 million subscribers (6% of global mobile subscriptions) at the end of 2019 and is expected to reach 1 billion subscribers by 2024. Many countries in the SSA region have more mobile-cellular subscriptions than their human population sizes (FAO, 2018; Kemp, 2019) with an approximate mobile density of 230 mobile subscriptions per 100 inhabitants. Smartphones account for a third (340 million) of mobile phones and are slowly taking over the "feature phones". The region's mobile subscriber penetration for all mobile phones is 50% (GSMA, 2020). The smartphone average adoption rate continues to rise and has reached 50% in 2020 (GSMA, 2020). The rate is expected to be much higher in some economically leading countries such as South Africa with over 90% penetration (Independent Communications Authority of South Africa (ICASA), 2020). This is because more affordable smartphone handsets are becoming more available on the market and are compatible with popular Apps and connections to 4G and 5G networks, which gives a much faster and better browsing experience than the traditional feature phones (Wyrzykowski, 2020). Daum et al. (2018) show that smartphone Apps can be designed to serve as reliable, affordable, and participatory data collection tools in complex smallholder farming systems. The use of more comprehensive mobile-phone-based technologies by smallholder farmers could, therefore, help them access the information necessary to support such complex farming systems (Krone et al., 2016).

The high number of mobile phone subscriptions, however, does not necessarily equate to an even distribution of the devices among the population. Regarding location within the country, gender, and youth dynamics, for example, SSA is highly characterised by unbalanced and wide disparities in terms of mobile phone ownership (Trendov et al., 2019). In some countries, rural people have far much less accessibility to mobile phones than urban dwellers (Nakasone et al., 2013). In Zimbabwe, despite a small gap, mobile phone use is higher in urban than rural areas (97% vs. 85%) (Moyo-Nyede and Ndoma, 2020). Furthermore, accessibility to mobile phones across the region varies considerably across countries. This varies from as high as 90% in Zimbabwe (Moyo-Nyede and Ndoma, 2020), 40% in Burkina Faso, and to as low as 15% in Niger, Chad, and Mauritania (Tsan et al., 2019). This vicious gap also characterises mobile phone ownership between men and women (Henze and Ulrichs, 2016; Messenger, 2018; Steinfield and Wyche, 2013). Sub-Saharan Africa's women are 15% less likely to own a mobile phone than men. Only 25% of the women who represent nearly 50% of all smallholder farmers in the region are registered users of digital for agriculture solutions (Tsan et al., 2019). Interestingly, a study by Isaya et al. (2018) shows that more than 86% of the female farmers in the Hai and Kilosa districts in Tanzania owned or has access to mobile phones. However, even if the majority of the women own mobile phones, they less often use them and have access to fewer services beyond voice communication than men (Isaya et al., 2018; Isenberg, 2019). On the other hand, a report by World Bank (2017) shows that many female farmers under *Esoko*'s mobile market information service did not own mobile phones and had to borrow from their children and/or husbands. Also, a study by Messenger (2018) shows that there was a gender divide in both Northern and Central Malawi as nearly 40% more men were owning mobile phones than women. Most women and girls who did not own mobiles had to share with their husbands, fathers, or mothers-in-law. Limited use of mobiles by women is worsened by the high costs of mobile phone data and airtime (Messenger, 2018). This gap, therefore, disproportionately reduces the productivity of women and the region. Moreover, there is little progress in trying to reach female farmers and reduce such gender asymmetries across the region (Krell et al., 2020). Isenberg (2019) argued that women especially from rural areas have remained an afterthought when it comes to ICT policy and private sector outreach.

Mobile network coverage continues to exponentially expand in SSA. The coverage complements the full functioning of mobile phones and hence their support towards smallholder agricultural development. Recent GSMA and ITU reports issued in 2020 have shown that more than 90 percent of the world population have access to or are currently within range of a mobile broadband signal, while more than one-third have access to 3G coverage (GSMA, 2020; ITU, 2020). In SSA, 3G network coverage expanded to 75% compared to 63% in 2017, while long-term evolutions (LTE) such as the 4G doubled to nearly 50% compared to 2017 (GSMA, 2020; Wyrzykowski, 2020). However, the region still accounts for 40% of the world population not covered by the mobile broadband network (GSMA, 2019). Countries such as Guinea Bissau have a very low proportion of their population (8%) with access to network signal compared to other developed economies including, the EU Member States, Barbados, and United Arab Emirates with 100% coverage (Trendov et al., 2019). Despite the region still lagging compared to others, the 5G era has begun and is gaining momentum. Thus, by end of 2025 SSA is expected to have just under 30 million mobile 5G connections (GSMA, 2020). Key trials on 5G have been conducted elsewhere in SSA, including countries such as Gabon, Kenya, Nigeria, and Uganda. The first major 5G networks were launched by Vodacom and MTN in 2020 to offer 5G mobile and fixed wireless access (FWA) services to many locations across South Africa (GSMA, 2020). However, a key concern is that despite all urban areas being virtually covered by a mobile broadband network, many gaps subsist in rural and remote areas where most smallholder farmers are located. In this context, innovative strategies, novel business models and supportive government and regional policy frameworks should be key in improving the commercial feasibility of increasing mobile internet broadband networks.

The Internet Connection in SSA

The use of the internet has continued to grow across the world (AGRA, 2015; World Bank, 2016). Mobile internet adoption for SSA was standing at 26% at the end of 2019 (GSMA, 2019). Accessing the internet unlocks the possibility of driving smallholder agricultural production through ICT-based strategies. The continuous penetration of mobile phones is key in advancing the use of the internet especially among the smallholder farmers located in rural areas (Qiang et al., 2012; Wyrzykowski, 2020). This is because much of the online activities take place on mobile phones (GIZ, 2018; ICASA, 2020). In 2017, nearly 50% of the global population had access to mobile phone internet, and most of them were in Africa and Asia (Trendov et al., 2019). In Africa, countries such as Kenya, Nigeria and Ghana registered the highest rate of mobile internet traffic in 2019 (Trendov et al., 2019). According to ICASA (2020), mobile phones are the most used means of accessing the internet by the majority of rural households in South Africa (45%). However, the internet connection is much lower in the majority of SSA countries with cases such as Ethiopia with only 4% of its population accessing the internet (Tsan et al., 2019).

Despite more and more urban people across the region becoming connected, rural people have remained disconnected and isolated. Thus, a huge gender gap and the rural-urban gap in mobile internet use persist in SSA (Wyrzykowski, 2020). The rural-urban gap in internet use is standing at 60% (Wyrzykowski, 2020). Approximately 40% fewer women are likely to use mobile internet than men in the region (ITU, 2020). However, in China, the proportions are almost similar for males and females, with a marginally higher figure for females (52.4%) (Trendov et al., 2019). This implies that

SSA has a larger gender gap in terms of internet access than other regions, indicating the importance of programs targeting women to increase internet usage in the region. Youths are important users of the internet in SSA. About 40% of the youths use the internet in Africa and the rate of adoption is sharply increasing (ITU, 2020). Given the sharp rise in internet usage and mobile uptake by the youth in developing countries, promoting youth engagement in agriculture could substantiate the adoption of ICTs in smallholder farming. However, in a study by Messenger (2018), mobile-based internet was the least used form of communication even in areas where nearly 50 percent of the people owned internet-enabled mobiles.

Trendov et al. (2019), argued that the penetration of mobile phones and the delivery of internet and mobile network connectivity especially in rural areas of SSA has remained a tall order and this is due to several constraining factors. It is, therefore, important to identify and address these factors as efforts seeking to improve the implementation of ICTs.

Factors Constraining the Use of Mobile Phone and Web-based Technologies by Smallholder Farmers in SSA

Illiteracy and lack of digital skills among smallholder farmers and in some cases extension agents constrain the use of ICTs (Messenger, 2018; Trendov et al., 2019). Owning and using a mobile phone may not be sufficient to justify productivity among farmers. Instead, farmers' skills level in operating the phone and understanding its features are critical (Quandt et al., 2020). Many studies have argued that lack of skills impedes the adoption of technologies and reduces the opportunities for smallholder farmers to access agricultural information and services in real-time (Henze and Ulrichs, 2016; ITU, 2020; Misaki et al., 2018). Together with Southern Asia, SSA has the lowest digital literacy rates (Trendov et al., 2019) with skills among smallholder farmers in countries like Ethiopia being nominal (Tsan et al., 2019). This is worsened by weak awareness and training on the new mobile and internet-based technologies and their potential towards agrarian change (Adebo, 2014; AGRA, 2015; Misaki et al., 2018). Therefore, fostering literacy and appropriate digital skills, especially among the youths, women and the elderly will be essential in keeping pace with the process of digital transformation and the building of digital societies (Misaki et al., 2018; Steinfield and Wyche, 2013; Trendov et al., 2019).

The high level of technological complexity is a barrier to the adoption and use of most existing mobile and web-based innovations. According to Featherman and Pavlou (2003) and Kotze, Anderson, and Summerfield (2016) besides acceptance and adoption processes, risk perceptions may strongly influence the individual's decision when dealing with complex technologies. Also, despite this being compounded by a lack of skills, old age, poor education, and language barriers, particularly in smallholder farming systems (Misaki et al., 2018; Trendov et al., 2019), innovations targeting farmers in that sector should be simple and tailored for their situations. For example, illiterate and older farmers can be supported by simple text-based innovations using local languages instead of sophisticated applications.

High costs of ICT devices such as mobile phones (smartphones), computers and costs of accessing network signal and the internet are fundamental barriers to the adoption and use of ICTs including mobile phones by various smallholder farmers (Krell et al., 2020; Misaki et al., 2018; Trendov et al., 2019). According to AGRA (2015), despite having access to mobile devices and services majority of the women and young people especially rural youth fail to meet the costs of maintaining the devices, buy airtime and data. However, Wyrzykowski (2020), reported that the average cost of mobile devices decreased from 57% of monthly income in 2015 to 30% in 2019 in SSA.

Unavailability and poor connectivity of both internet and mobile network services are additional barriers to the use of mobile technologies by smallholder farmers especially in remote areas (AGRA, 2015; Messenger, 2018; Trendov et al., 2019). Thus, the speed and quality of broadband services are generally poor in rural areas compared to urban areas in most developing countries (ITU, 2020; Steinfield and Wyche, 2013). Ultimately, these factors negatively impact the introduction and operationalisation of ICTs for supporting smallholder farming systems.

The costs of ICT-based and telecommunication equipment and technical infrastructure supplies such as satellite systems, servers, telecom towers, fiber optic cables, and voice over internet protocols (VoIP) especially in rural farming areas are a great concern to investors and developers (AGRA, 2015; Roy, 2009; Statista, 2020). Besides being costly, investments in such technologies are considered risky (World Bank, 2017), and hence their establishments seem uneconomical to them (AGRA, 2015). However, as argued by Roy (2009), it is possible to easily overestimate these costs and underestimate the cumulative benefits which can be brought by the technologies. In line with these factors, most farming communities lack digital infrastructure due to the investment costs associated with them. Despite the economic disruptions caused by the Covid-19 pandemic, GSMA (GSMA, 2020) expects major operators in the SSA region to have invested over USD50 billion in infrastructure rollouts between 2019 and 2025.

Availability of electricity especially in rural farming areas is unreliable and has broadly curtailed access to and use of ICT-based innovations in smallholder farming areas (Abebe and Cherinet, 2019; AGRA, 2015; Roy, 2009). This has not only impacted the introduction of new technologies in the areas but also on the everyday activities and businesses such as repairing and charging mobile phones (Abebe and Cherinet, 2019; Ogutu et al., 2014). Carefully planned Public-Private Partnerships (PPPs) can be effective instruments to support the expansion and availability of electricity and its distribution support infrastructure to previously underserved areas and communities (Ogutu et al., 2014; SNRD, 2016; Wyrzykowski, 2020). Furthermore, investments in solar energy as a cheaper and cleaner alternative should be supported to sustain the power supply in rural areas.

Cultural attitudes and social norms (e.g., gender norms) that characterise most parts of the smallholder farming communities in SSA often discriminate against women's access to technology (FAO, 2018). This is because, the current ICT-based technologies for supporting smallholder farmers lack services designed to meet the needs of women farmers (Batchelor et al., 2014). Also, it could be because women are generally perceived to be vulnerable to abuse from men when allowed to work with mobile phones (FAO, 2018). However, Kotze et al. (2016) note that women's limited adoption of high-tech products could be because they are less optimistic and have higher levels of risk aversion than men. Therefore, this generally implies that improving women's access to and use of mobile phones and the internet breaks some of these gendered barriers and can improve smallholder agricultural productivity since women are the majority producers in that sector (Zyl et al., 2014).

Application of Mobile and Web-based Technologies to Improve Smallholder Agricultural Extension Services: A Critique of Case Studies in SSA

There are various agricultural mobile applications (Apps) and web-based platforms being implemented to support agricultural extension delivery and transformation of smallholder farmers in SSA (Costopoulou et al., 2016; Daum et al., 2018; World Bank, 2017). Given the need to address heterogeneous and complex farm management issues within the smallholder sector (Consolata, 2017; Costopoulou et al., 2016), the "App economy" is constantly evolving and also becoming complex (ITU, 2020; Krone et al., 2016). This review identified five key applications being currently used to improve extension services delivery in SSA. These include Esoko, iCow, Community Knowledge Workers (CKWs), WeFarm, and DigiFarm. Although this is by no means an exhaustive list, a review of these identified few innovations creates an awareness of their development, uses, impact and general limitations.

Esoko

Esoko is a technology platform focusing on bringing marketing information to farmers across Africa. It was established in 2005 in Ghana, and currently operating in 16 African countries including Nigeria, Sudan, Malawi, Kenya, Uganda, Rwanda, and Zimbabwe (AGRA, 2015). Its main objective is to empower smallholder farmers by making farming more profitable through access to agricultural information and markets (Van Schalkwyk et al., 2017). The initiative was initially designed to be a market intelligent tool for improving the availability of markets to smallholder farmers and businesses (Asare-kyei, 2013; David-West, 2010). However, within the first 5 years, it expanded into a wide-ranging platform extending its services to cover weather forecasting, crop production advice, and becoming an advertising platform for farmers and the agri-business community at large (AGRA, 2015; Qiang et al., 2012).

Some of Esoko's major activities involve the use of customised survey forms on mobile phones, tablets, or web-connected laptops to collect real-time data on market prices (farmgate, retail, or wholesale) and profile data for users (farmers, traders, transporters, and agents), which is constantly uploaded on the system (Asare-kyei, 2013). The enumerators as well as anyone can upload bids and offers to buy or sell agricultural products and services on the platform. The registered members are then categorised by location, commodity, and occupation and will receive automatic and personalised price alerts, buy and sell offers through text messages. Anyone can also upload offers using the online web and Esoko automatically sends the bids or offers via mobile phones whenever there is a match between a buyer and seller. Besides marketing services, the registered farmers periodically receive bulk SMS as reminders for farming activities or advice on certain farming practices and weather forecasts (Asare-kyei, 2013). The Esoko platform also has a call centre called "Helpline" where farmers can directly acquire expert advice (Van Schalkwyk et al., 2017).

In terms of its scalability, by 2017, the system was already serving more than 350 000 farmers in 10 countries across Africa (Van Schalkwyk et al., 2017). Until that year, approximately 9.5 million messages were collected from 70 markets and shared on the platform. Despite smallholder farmers being initially the main target clientele (GSMA, 2020), the Esoko platform has further expanded its services to target major agribusinesses, network operators, NGOs, and government ministries (Van Schalkwyk et al., 2017). In Zimbabwe, the Esoko mobile platform which started its operations in 2012 was servicing more than 17 fresh produce markets, covering 33 agricultural commodities, and supporting over 170 000 smallholder farmers across the country by the end of 2015 (Ifeoma and Hove Tawanda, 2015).

One of the main challenges faced during the implementation of Esoko was that the existing content of market information could not be digitized and or commercialised. Thus, content collected from the field was largely inaccurate, stale and not accepted by farmers (Asare-kyei, 2013; Van Schalkwyk et al., 2017). Esoko developers had assumed that data from central sources like government publications were readily available and of good quality. They, however, addressed the challenge by creating their content of market information to meet the target market demand. Also, during their initial implementation process, developers noticed that instead of pushing content into the Esoko system as anticipated, more business was made by pulling out data from the system. This was data demanded by buyers and other service providers seeking to understand the needs, locations, and farming activities of farmers (GSMA, 2020). In addition, based on its initial development experience, Esoko realised later that most of its partners were inexperienced in farmer training and did not understand mobile phone technologies. This has resulted in them investing more money to create a consulting-like capacity from within to ensure its effective deployment and the training of farmers. However, in moving forward, the system is well-placed to continue fighting gender imbalance in its client base as it seeks to facilitate access to its services by more women farmers (www.esoko.com)

The Community Knowledge Worker (CKW)

The Community Knowledge Workers initiative was launched in 2009 in Uganda by Grameen Foundation to help in delivering agricultural and marketing information to smallholder farmers located in the rural areas of Eastern and Northern Uganda. Its main objective was to achieve impact at the farm level by providing rural advisory services to remotely located smallholder farmers through a combination of technology and human network (peer advisors) (a form of farmer-to-farmer extension) (Grameen Foundation, 2014; Van Campenhout, 2017). The system uses locally recruited farmers/villagers (referred to as CKWs) to further expand the reach of the government's rural advisory service workers (Van Campenhout, 2017).

The CKW system offers its services free of charge to farmers and relies on donor funding to support its activities. Agents of CKW work in partnership with other organisations known as service partners. The Uganda National Agro-Inputs Dealers' association is one of the partners providing information on input agri-suppliers across the country (Van Campenhout, 2017), while Makerere University and the National Agricultural Research Organisation (NARO), provides crop and livestock information (Amadu et al., 2015). In Kenya, where CKWs are known as Village Knowledge Workers they work in partnership with Farm Concern International, which is an organisation that focuses on market development and smallholder commercialisation organisation (Amadu et al., 2015).

In recruiting the CKW agents, community members with facilitation from Grameen Foundation nominate individuals from community farmers' groups based on key requirements, including education qualifications, leadership skills, residency in the community, trustworthiness, community respect, readiness to be early adopters of new ideas and willingness to devote some time per week to carry out extension work. Nominees are interviewed, and potential CKW agents are given Android smartphones, which are pre-loaded with an in-house developed mobile application (CKW App suite system) and then trained on how to use it (Grameen Foundation, 2014). In addition, the CWK agents, receive a bicycle, and solar power equipment on loan arrangements which assist them in delivering services. The CKW system uses three major applications namely, CKW Search, CKW Pulse, and CKW Survey (now called TaroWorks) (Amadu et al., 2015). The CKW Search comprises a searchable library where CKWs can check for agricultural, weather and marketing information requested by the farmers and feed into the central repository to target extension and marketing services providers (Qiang et al., 2012; Van Campenhout, 2017). The agents use the internet and the App to access information from the repository and convert it into contexts that are understandable to local farmers when delivering the messages (Amadu et al., 2015; McCole et al., 2014). The CKW Pulse allows agents to communicate directly with experts at the CKW headquarters to access monthly targets and monitor their progress. All data collection or surveys are, therefore, done using the TaroWorks app. The TaroWorks and CKW Search Apps can both operate online and offline allowing the agents to search for information or track farmer activities in areas without cell phone coverage. All information cached offline is later transmitted to a remote server called "Salesforce" when the CKW agent comes within cell phone network coverage (Amadu et al., 2015). All activities of CKW agents are supported by call centres operated by agricultural experts to address concerns raised by farmers (McCole et al., 2014).

The CKW system has since been replicated in many other African and Asian countries like Kenya, Ghana, India, China and Indonesia. In 2014, the CKW together with its partners had completed over 100 000 unique interviews and 1.5 million total interactions with over 300 000 of its registered farmers across the 43 districts in Uganda (Grameen Foundation, 2014). In Indonesia, the CKW programme, Ruma, reached over a million clients in 2014. Thus, Amadu et al. (2015) note that CKWs are creating a greater impact especially by serving remote areas "last mile principle" where poor road networks and infrastructure often discourage the government extension agents from visiting. Furthermore, one of the strengths of CKWs is that farmers do not necessarily need cell phones to receive agricultural information as the agents use their smartphones to acquire information and physically provide the information to farmers. The CKW agents are paid monthly, and incentives are also given to top achievers as a way of motivating them.

In a study by Van Campenhout (2017), to assess the impact of CKW on crops grown by beneficiary farmers in Uganda, results show that the presence of CKWs increased the percentage of farmers growing high-value cash crops such as coffee and beans. However, the intervention was found to have reduced the total number of farmers growing food crops such as millet, cassava, and sweet potatoes. This can be attributed to the improved access to marketing information for higher-value cash crops by the farmers. In the same study by Van Campenhout (2017), farmers who had access to the CKW system received prices that were on average 12–16% higher than those without access.

One of the main limitations of the CKW is that through the nomination process, the villagers might select popular members who lack the right motivation for smallholder agricultural information services delivery. Also, favoritism, jealousy, nepotism and community politics may influence the nomination process. Thus, agents could only be motivated to work on repaying smartphones and bicycles acquired on credit than providing better quality extension service to their peers (Amadu et al., 2015). In that regard, Grameen Foundation provides little remunerations and commissions to motivate its agents. Also, Misaki et al. (2018) note that lack of mutual understanding and commitment including diverging visions with partners caused tensions that limited the effective outreach and scalability of the initiative. For example, the CKW operations were terminated and forced to lay off in Massaka District, Uganda after the closure of one of their key partners (East Africa Dairy Development project) in 2013 (Amadu et al., 2015).

In looking forward, the CKW considers the importance of using a fully blended multi-channel approach to improve the effectiveness of the extension services in reaching needy farmers.

iCow

The iCow is a comprehensive mobile phone-enabled agricultural information platform that was launched in 2011 in Nairobi, Kenya. Its main objective is to enable modern cow farming techniques, technological solutions and improved information to be disseminated to smallholder livestock producers who do not have access to large, and industrialized resources (Lexi, 2014). It is a mobile agricultural App that assists in improving access to good agricultural practices in real-time and upscale the smallholder livestock farmers in East Africa (www.icow.co.ke). The iCow App runs on a fee-for-service model with users being charged a premium rate-SMS for all services obtained through the system. It generates its income through a revenue-share model with Safaricom (mobile network company) and through third-party users interested in data, reports or having a presence in the content. The iCow's services are offered by Green Dream Technology (GDT) in partnership with Safaricom Foundation and International Livestock Research Institute (ILRI).

The App has been designed to work on both basic (features) and smartphones and can be accessed in multiple languages while covering various aspects of farming (Livestock, Crops and Soils) delivered through SMS and voice. The iCow system has many features and is always being constantly developed. 'Mushauri' is a platform that provides education and advice to subscribed users (livestock farmers) by sending weekly 'tips' on husbandry practices and management. 'Kalenda' consist of calendars that are customisable to individual cows (Cow Kalenda), calves (Calf Kalenda), and heifers (Heifer Kalenda) for use by farmers in livestock management. "iCow Soko" is a marketplace for farmers to buy and sell the products they produce and those not available in agro-dealers. Potential buyers receive the contact numbers of sellers through the iCow platform. 'Vetenari' provides access to a database of registered vets and support services. The iCow platform, therefore, effectively performs as a virtual veterinary nurse, midwife, and farm management consultant, providing information to the farmers on cow gestation, milk production as well as health and nutrition (Lexi, 2014). Farmers registered for the service can create profiles or register their animals by capturing key data about individual cows, including insemination dates and anticipated calving dates. Such data will be used by experts in developing tailored information and timely reminders for all important husbandry practices and sent to the farmers every week (Marwa et al., 2020).

The iCow App has been replicated in Tanzania and Ethiopia in 2016. At inception in Kenya, it had only 4000 farmers but has increased to over 580 000 users since 2011 (CTA, 2017). Some farmers who started using iCow since its launch in 2011 have reported some substantial benefits including a 51-75% increase in their overall efficiency (Lexi, 2014). For example, one of the farmers reported significant increases in milk yields of up to 30 litres from the previous 15 litres as well as improvement in the general health of the animals (Lexi, 2014). Also, farmers using Mashauri and those who had stayed on the platform for longer periods reported reduced veterinary costs, diseases and calf mortality incidences. According to Marwa et al. (2020), iCow services in Kenya have increased annual milk production per cow, income from milk sales, and household income by 13%, 29%, and 22%, respectively.

The iCow's main limitation was a lack of awareness. In a study conducted by Dolan and Burns (2014), the iCow App was reported to be unknown to dairy cooperative farmers located within a four-hour radius of the company's base in Nairobi

WeFarm

WeFarm is a farmer-to-farmer digital network and social enterprise founded in 2015 in Kenya. Its major aim is to connect smallholder farmers across the region in solving challenges, sharing ideas, and spreading innovation. Thus, users can share information irrespective of their type of agricultural enterprise, location, language, or place across the value chain (Ellie, 2015; Henze and Ulrichs, 2016). Its services can be offered without having to travel or spend money and most services can be accessed by the farmers without an internet connection. Thus, WeFarm's key novelty is the creation of the region's first crowdsourced peer-to-peer farmer network especially for communities without internet access. The system's SMS service App enables farmers to present questions through free SMS shortcodes and receive crowd-sourced responses from other registered users (Henze and Ulrichs, 2016; Trendov et al., 2019). WeFarm uses the internet to process messages through a series of custom-built machine learning applications and share with other users to respond and provide answers (Ellie, 2015). Every message is categorized with many tags that define its intent, language used and content, and in that process, the system picks the best-matched responses or answers and relays them back to the farmer as SMSs. Currently, users can communicate in three main African languages; Kiswahili, Luganda, and Runyankore, which are used in addition to English (WeFarm, 2018). Farmers also use the platform to access agricultural inputs like seeds and fertilizer and non-agricultural products including cooking stoves, solar panels, and mobile phones (Mackay, 2019).

The WeFarm platform reached over 2 million users across Kenya, Uganda, and Tanzania by 2018 (Mackay, 2019). WeFarm is reported to have helped small-scale farmers improve productivity, gain insight into prices, able to fight impacts of climate change, access agricultural inputs, and diversify their farming interests. With one in five farms in Uganda and Kenya being able to use the

WeFarm network, in a single calendar month in 2018, farmers managed to ask and answer over one million questions (WeFarm, 2018). According to Mackay (2019), the system achieved 1USD million in sales in the first few months of launching its marketing place.

One of the major limitations of WeFarm is its limited curation given that it works at a regional scale with farmers from very diverse ecological and socio-political farming environments. Thus, despite being able to break the language barrier and its ability to use machine learning tools to select the best crowd-sourced answers, its ability to moderate farmer-to-farmer skills exchanges and select appropriate responses is questionable. Also, despite allowing farmers to present their questions for others to provide advice, the system does not offer direct interactivity among farmers including ongoing discussions and probing for better explanations. Thus, it practically simulates an end-to-end information exchange which is more silo-based as the content receiver does not know exactly where the solution came from (FAO, 2017).

DigiFarm

DigiFarm is an integrated mobile-based system developed to offer convenient, and one-stop access to a diversity of digital services tailored for smallholder farmers (SVAI, 2018). In 2016, Safaricom partnered with Mezzanine to establish the DigiFarm platform which was launched in 2017 in Kenya. The initiative's objectives were to create statistical data on farms and farming activities conducted in Kenya, create a farmers' marketing platform, and improve access to extension services, and financial services by the farmers (Shrader et al., 2019). Since Safaricom lacked expertise in delivering all services, DigiFarm draws on a wide range of skills from many other partners including, iProcure (providing inputs), FarmDrive (managing the loan book), Arifu (providing learning content/modules) and iShamba (providing digital and video learning content) (Denyes et al., 2018). Besides many services it provides, DigiFarm, also, serves as a national database that captures statistical data of all farms and farming activities in Kenya. This data is expected to assist in long-term planning and the provisioning of customised solutions to the farmers. In addition, smallholder farmers are using DigiFarm's loan module to apply for small loans particularly for buying production inputs such as livestock feed, and can pay via a mobile bank account and payment App (M-Pesa) (SVAI, 2018).

DigiFarm is a text-based platform that is accessible using either basic feature phones or smartphones and farmers do not pay for the service. Farmers can register or sign up to the platform by capturing details about their farms and farming activities or they can register through agents such as Kenya Livestock Producers Association (KLPA). All users registered on the platform, have access to a suite of products and services that the ecosystem offers. These include extension services via learning modules, electronic vouchers for buying inputs, training on different farming activities, and general advice on agriculture and animal husbandry practices.

When DigiFarm was launched, it registered more than 700 000 farmers in the first year with a 35% active rate and as of May 2019, the platform was hosting more than one million registered farmers and expecting to reach 5 million users in 2023 (Denyes et al., 2018). In 2018, nearly 310 000 smallholder farmers accessed DigiFarm's educational content through its learning partners such as Arifu with more than 2 million interactions on the service (Shrader et al., 2019). The system continues to evolve with new sub-Apps being introduced, including DigiSoko, an open marketplace for agricultural produce (Shrader et al., 2019). Currently, government agents, input providers, financial institutions, and other agri-service providers can network with and reach out to smallholder farmers with agricultural-related services. Over 50 000 farmers purchased inputs through iProcure in 2018 and many of the users were repeat customers (Shrader et al., 2019).

DigiFarm's limitations include lack of direct promotion and real-time farmer-to-farmer learning or interactivity for skills and innovation exchange. Therefore, it does not guarantee the provision of localised extension solutions to farmers. Another limitation is the very low participation by women on the platform (Denyes et al., 2018). In trying to address this challenge, DigiFarm has engaged KLPA, and other registration point service providers to ensure a more effective way of engaging with women and improving its system functionally to remove any aspects that might discourage women participation.

General Limitations and Prospects of Improving the Existing ICT-enabled Initiatives Used in Agricultural Extension Services in SSA

Generally, the involvement of farmers (end users) in the development process of many of the above-mentioned ICT-enabled initiatives is limited. Although the initiatives do address some pertinent farmer constraints and challenges, they are being created without substantive research-based needs assessment information (Tsan et al., 2019). Limited farmer involvement in the initial phase of inventing digital technologies for use in agriculture has been described by World Bank (2017) and Misaki et al. (2018) as a common issue in many developing countries. However, for the technologies to generate demonstrable value, they must be created based on the multidimensional needs and experiences of the end-users (Dolan & Burns, 2014; Emeana et al., 2020; Konaté et al., 2020). A study by (Henze and Ulrichs, 2016) in Kenya suggested that end-user involvement in the development process can enhance the applicability and usefulness of the interventions. Primarily, it can boost user trust, and this often allows the innovation to continue even after donors have pulled out (Zyl et al., 2014). A lack of preliminary market research caused the deployment framework of Esoko system to be changed on two separate occasions as it failed to meet the needs of the users (David-West, 2010). This is because not involving users will cause them to perceive the newly introduced technology as a foreign tool or forced innovation (Costopoulou et al., 2016) and this later affects adoption. A previous study on mobile Apps for agriculture by (Costopoulou et al., 2016) also in the global mobile ecosystem showed that the mobile agricultural apps had a low rating in stores' related tags indicating that they did not meet needs of agricultural stakeholders.

Baseline surveys are fundamental and should be a component of the development processes of innovations including digital-based agricultural solutions or supporting smallholder farmers. While this may sound to be apparent, a review of the existing technologies shows that many developers overlook this step. According to Tsan et al. (2019), such innovations, therefore, lack rigor and robustness because they do not have baseline data and indicators to enact their continuous monitoring, evaluation, and future improvements. Consequently, impact metrics for most of the innovations developed without baseline information are inaccurate and unreliable because they will be largely based on hypothetical and anecdotal evidence (World Bank, 2017). A study by Ochieng et al. (2014) acknowledged the presents of several challenges in assessing the impact of ICT-based market information services on smallholders' farm input use and productivity in Kenya.

Based on this review, it can also be deduced that the creation of extension content and its dissemination within the current initiatives is not farmer-driven (Tsan et al., 2019). While farmers can present questions to agricultural experts and fellow farmers for advice through the technologies such as WeFarm, CKW, iCow, DigiFarm, and Esoko, direct and real-time farmer-to-farmer learning or interactivity for skills and innovation exchange is not provisioned. According Nakasone et al. (2013) and Costopoulou et al. (2016), in developing countries and global ecosystem, most existing mobile and web-based innovations simulate principal-agent linear-based models just like conventional extension systems. Thus, solutions linearly flow from experts to farmers which makes the farmers just content receivers of the pre-determined agricultural information and services (World Bank, 2017). Anjum (2015) reported that most farmers experienced problems with the Mobile Multimedia Agricultural Advisory System (MAAS) in India due to the limited knowledge of agricultural experts at the call centre. The farmers were receiving poor-quality information, which was untimely, inaccurate and unreliable. However, interactive and participatory innovations and approaches can generate significant opportunities for multi-directional information sharing leading to demonstrable impacts for the smallholder farmers and these are encouraged (World Bank, 2017). They allow farmers, to work with content that is validated by them and shared by their peers which influences the generation of customised information, services, and inputs that suits their needs (Konaté et al., 2020). A recent study by Krell et al. (2020) in central Kenya demonstrates the importance of linkages between ICT technology adoption rates and the role of informal and formal farmer groups. Thus, farmer groups allow farmers to co-create, process and share information about their own experiences among themselves with extension agents and researchers being facilitators and not teachers (Franzel et al., 2015). This, also, presents new prospects for documentation of farmer-driven innovations which define traditional knowledge (World Bank, 2017).

Generalizability at the farm and community farming system levels seems to be limited across the existing mobile-enabled agricultural applications. The findings of Anadozie et al. (2021) in North-East Nigeria indicates that most of the ICT-based initiatives targets a few isolated farm enterprises or specific objectives of interest rather than accounting for the whole farm system holistically. However, system-based perspectives emphasize the need to view a farm or farming community as a whole and not as separate strata (David and Samuel, 2014). As such, platforms such as Esoko which aimed to provide farmers with only a narrow stream of market information ended up facing scalability challenges (AGRA, 2015; GSMA, 2013). This is because what it initially offered became incompatible with demands coming from developing markets which required a broader coverage of various agricultural products and services (Van Schalkwyk et al., 2017). According to Marwa et al. (2020), the iCow platform which started as a virtual veterinary nurse only for dairy cows also lacked generalizability since it was not covering other classes of cattle such as beef animals and important activities such as forage production, milk processing, and marketing.

This study has similar observations to Costopoulou et al. (2016), who reported that many agricultural apps for smallholder farmers were being designed and developed without adequate input from other key stakeholders, including research institutions and government extension departments. Therefore, Garforth and Lawrence (1997) posited that such innovations often fail to meet the needs and requirements of the targeted users. For example, most of the new technologies are being developed in isolation (SNRD, 2016) and are running as parallel models to the existing public extension model. However, a public extension system is a fundamental source of information, and promoter of technology adoption by farmers, and a bridge to the farmer-research linkage (Ali, 2012; Mapiye et al., 2019; SNRD, 2016). Thus, the new technologies require the active involvement of public agencies especially the extension agents (Costopoulou et al., 2016; Karanja et al., 2020; Mabe and Oladele, 2015). It also requires strategic private partners to improve its sustainability. This is despite partners like most mobile network organisations want exclusivity and to support manly those Apps that are already operating at scale (Batchelor et al., 2014; Qiang et al., 2012). Zyl et al. (2014) argued that adequate collaboration with various other strong institutions is important because it increases the trust of farmers to work with the innovations. Therefore, as suggested by Danes et al. (2014), the technology developers need to build on the existing networks of government extension, fellow farmers, known traders, research institutions, NGOs, private companies, and local consultants.

Another key limitation is that most smallholder farmers, especially the resource-constrained have low incomes hence are unable and or unwilling to pay for the use of mobile and web-based technologies (Krell et al., 2020; Qiang et al., 2012). Thus, Kaur and Kaur (2018) argued that many deployed technologies have often failed to scale up not because of their irrelevance, but because of the failure by farmers to pay for accessing them. For example, efforts to establish digital extension systems, such as iCow and RML Agtech in India through selling subscriptions to farmers resulted in the technologies reaching only a small fraction of the targeted users (Tsan et al., 2019). Thus, according to Qiang et al. (2012) report on mobile applications for agriculture and rural development, only 29 percent of the applications studied had sufficient revenue streams to cover operating costs. A lack of sustainable revenue streams ultimately affects the continuity of these technologies, especially after the donors withdraw their funding. Although it has been proven that low-income people are sometimes willing to pay small fees for innovations they believe will meet their needs (Drafor, 2016), the main challenge for developers is to convince farmers that their systems add value to farming and meeting that promise. Besides the issues of making the innovations affordable, the other challenge facing existing developers is how to make them accessible in venues and forms that are convenient to smallholder farmers (Dlamini and Worth, 2019). Therefore, to ensure better affordability and accessibility of the innovations especially by smallholders who may not afford to pay full-service fees, the development and implementation programmes require strong partnerships and extensive awareness campaigns with various key stakeholders participating (Zyl et al., 2014). Also, the farmers who are unable to meet the costs of acquiring smartphones and their advanced applications should be allowed to access innovations through alternative means (Ali, 2012) such as interventions designed to work with basic phones (Krell et al., 2020).

Apart from low income, many studies have indicated that lack of education and digital skills are also key factors that impede opportunities for the farmers to access relevant and timely agricultural information and services (Henze & Ulrichs, 2016; Misaki et al., 2018; Anjum, 2015; Dlamini & Worth, 2019). Some of these essential skills which farmers lack include the ability to register themselves and access the applications, update their profiles, and use various methods such as SMS, picture, audio, and voice to communicate Anjum (2015). In a study by Rashid and Laurant (2014), on International Development Research Centre (IDRC) supported projects in Canada, more than 90% of the farmers on the DrumNet App technology were not able to send an SMS for business purposes due to illiteracy. The effects of illiteracy and digital illiteracy among smallholders are being worsened by a lack of training and awareness campaigns about the innovations especially during the development and deployment phases (Danes et al., 2014; Dlamini and Worth, 2019). A study by Anjum (2015) in Bangladesh, found that almost all the farmers (99%) were not aware of a web-based agricultural market information system that was initiated and sponsored by the government implying a failure by the government to promote the system. Therefore, end-user training and awareness campaigns are critical in improving the adoption and usefulness of the applications (Abebe and Cherinet, 2019; Adebo, 2014). Besides the farmers, the extension agents and all targeted services providers working with farmers also require training and re-training to improve their skills and awareness (Mabe and Oladele, 2015). However as argued by Henze and

Ulrichs (2016), this could attract a huge cost factor especially for start-up technologies with limited funding.

Based on the review findings, the issue of gender imbalance remains a big challenge to the scaling and sustainability of the existing Apps. Innovations like Esoko and CKW struggled to close the gender gap and are introducing programmes that promote the inclusion of women. Also, the studies by Zyl et al. (2014) and Dlamini and Worth (2019), in Africa reported that far much fewer women compared to men had access to mobile and web-based technologies. In trying to address the gender imbalance some programmes such as the Up-scaling Technology in Agriculture through Knowledge and Extension (UPTAKE) in Tanzania which aimed to achieve 50% representation in its database have failed to reduce the gap (Karanja et al., 2020). Of the 55,710 farmers recruited for the programme, 73% were men while 27% women. This suggests the need for more strategies in improving the uptake of mobile and web-based technologies by women farmers and other vulnerable groups like youths and the elderly (AGRA, 2015; Karanja et al., 2020).

Scalability is one of the challenges which agricultural App developers face. The ability to build initiatives or systems that are self-sustaining beyond their initial grant funding periods is one primary factor compounding the problem of scalability (Grameen Foundation, 2014; McCole et al., 2014; Zyl et al., 2014). However, the report by Qiang et al. (2012) shows that over 50% of the mobile agriculture Apps studied globally achieved scalability during stage one of their development. In this review, the experience by Esoko shows that, despite the initiative demonstrably achieved better impacts, it could not immediately replicate itself virally because of the higher costs it incurred in bringing in new clients (GSMA, 2013). Esoko's overall deployment costs constituted 95% of the total costs incurred in building the technology (Van Schalkwyk et al., 2017). However, Henze and Ulrichs (2016) argue that despite having been offered a lot of funding during design and piloting, most of the new technologies perform poorly during their marketing and in-field deployment. Thus, the technical capacity of the innovations often fails even after the customer base is increased mainly because the developers underestimate the importance of marketing and capacity building of the technologies to various end-users before implementation (Danes et al., 2014). A group of USAID researchers discovered that the iCow platform, five years after its launch was unknown to dairy cooperative farmers within a four-hour radius of the company's base in Nairobi, (Dolan and Burns, 2014).

Conclusion

Smallholder farmers are essential players in achieving food security and poverty reduction in SSA. Despite the many ecological, economic, and institutional challenges constraining them, limited access to relevant and timely agricultural information and services is their primary challenge. Lack of access to relevant information and services affects their ability to address daily challenges and respond to opportunities. However, the penetration and propagation of mobile phones, the internet, and growth in mobile network coverage across the region have led to a surge in mobile services for rural smallholder agricultural systems. In response to this ICT revolution, currently, they are dozens of mobile and web-based agricultural technologies trying to promote access to agricultural information and services by smallholder farmers. Many of them are being implemented in Eastern and Central Africa implying and huge gap for Southern Africa. Most of the services are being offered through basic feature phones using SMS and voice, especially towards resource-poor households. However, with the current penetration and adoption rate of smartphones across the region (over 50%), focusing on their use could bring more positive impacts. This is because they allow audio, video and picture messages to be shared and are compatible with improved Apps and connections to 4G and 5G networks which give a much faster and better browsing experience.

Many positive developments and promising impact metrics are emerging from the application of the various initiatives in supporting smallholders. These include market linkages, access to production and weather information, and mobile banking services. However, most of the technologies have remained limited. Information and services dissemination still portray a linear and principal-agent arrangement where farmers are receivers of pre-determined information and services. End-users of the technologies are not being included in the whole development process and this affects the adoption, scalability, and replicability of the technologies. Limitations such as illiteracy and digital illiteracy, language barrier, lack of strategic partnerships, gender disparities, and poor training and awareness campaign continue to hamper the development and sustainability of the initiatives. To improve adoption of the innovations and ensure optimal productivity of smallholders through better access to information and services, it is important to address the identified challenges and promote Private-Public-Partnerships to ensure availability of funding, implementation of customised training and awareness programmes targeting the smallholder farmers. The review findings, therefore, provide useful directions to the researchers, governments, and developers of mobile phone-based systems in developing sustainable ICT-based technologies for smallholder farming systems.

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