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Can digital solutions transform agri-food systems in Africa?

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ABSTRACT

Digital agriculture solutions hold a promise to build agri-food food systems that are more efficient, environmentally sustainable, and inclusive, thereby contributing to the attainment of the Sustainable Development Goals. In most African countries, the rapid adoption of mobile phones and other digital tools have accelerated the deployment of agricultural services for farmers and other value chain actors resulting in enhanced access to information, knowledge, financial services, markets, and farm tools. In addition, the COVID-19 pandemic has provided a unique opportunity to fast-track the deployment of contact-free digital solutions along the agri-food value chains. Despite the numerous opportunities presented by the digital agricultural revolution, its potential to transform agri-food systems in Africa remains uncertain. With a broad perspective on Africa, this paper explores the emerging evidence on digital agricultural services including key drivers, evidence on impact, and the effects of the COVID-19 pandemic. The paper concludes with some implications for policy makers and professionals in agricultural economics.

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1. Introduction

In most Sub-Saharan African (SSA) countries, growth of the agriculture sector is a *sine qua non* to economic development and the achievement of the Sustainable Development Goals. According to the recent estimates, agriculture contributes about 53% of total employment (International Labour Organization 2021) and about 16% to Gross Domestic Product (GDP) in SSA economies (World Bank 2022). About 60% of all Africans live in rural areas and most depend on agriculture as their main source of livelihood. The contribution of agriculture is highest in poorer countries: for example, in Malawi, the agricultural sector contributed 26% to gross domestic product (GDP), 64% to its total employment and 72% to exports revenue in 2017 (Mangani et al. 2020).

Fuelled by a fast-growing population, expanding middle class, rapid urbanisation, and evolving dietary preferences, Africa's food demand continues to grow rapidly. The total value of the agri-food market beyond on-farm production is projected to reach one trillion dollars per year by 2030. Africa's food and agricultural imports, estimated at $45-$50 billion dollars in 2020 (Pais, Jayaram, and van Wamelen 2020), are projected to be as high as US$110 billion by 2025. Moreover, the COVID-19 pandemic has highlighted critical vulnerabilities in global food systems and placed even greater pressure on food insecure regions (Morsy, Salami, and Mukasa 2021). A recent study evaluating the socioeconomic impact of COVID-19 on four Ethiopia, Malawi, Nigeria, and Uganda reveals that 80% of the population, about 258 million people, have lost their source of livelihoods from the pandemic (Josephson, Kilic, and Michler 2020).

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On the supply side, agricultural productivity in Africa lags far behind the rest of the world. The farming sector is dominated by smallholder farmers who produce 85% of Africa's agricultural output. Much of the African continent is yet to experience the Green Revolution that boosted agriculture productivity in other regions of the world since the 1960s resulting in a significant yield gap especially for key cereal crops. For example, in 2019 Africa had slightly more land under maize production (about 41 million hectares) than the United States of America (about 33 million hectares). On this land, the USA produced about 347 million tonnes of maize grain compared to only 82 million tonnes for Africa, a more than fivefold yield gap (FAOSTAT 2021). This yield gap between Africa and the rest of the world has been mostly attributed to limited use of productivity enhancing technologies such as irrigation, chemical fertilisers, mechanisation and improved seed (Dossou-Yovo et al. 2020; Leitner et al. 2020).

Against this background of increasing food demand and low agricultural productivity there is a growing expectation that digital technologies can help transform the agri-food sector in Africa and build back better, more efficient and resilient food systems (Jellason, Robinson, and Ogbaga 2021). Moreover, digital solutions have the potential to link agriculture closer to industry, services, and other economic sectors, thereby creating significant multiplier effects. With a broad perspective on Africa and a spotlight on South Africa, this paper explores the emerging evidence on the key drivers of digitalisation, the status of digital agriculture tools, assessment of development impacts, and the effects of COVID-19 pandemic. The paper concludes with some implications for policy makers and professionals in the field of agricultural economics.

2. Lexicon and taxonomy

Before exploring aspects of digitalisation[1] of agri-food systems in Africa, a few definitions are in order to establish a common understanding lexicon and taxonomy. Digital agriculture refers collectively to agricultural practices that digitally collect, store, analyze, and share electronic data and information along in agri-food systems to improve efficiency (Tsan et al. 2019). Early reference to this phenomenon dates back to the mid-1990s under the term "information and communication technologies for agriculture" commonly abbreviated as ICT4Ag (Auburn and MacLean,1993). Currently, several terms are used somewhat interchangeably to describe the same phenomenon including "smart agriculture", "precision agriculture", "e-agriculture", "smart farming", "agriculture 4.0", etc. Whatever the terminology, digital agriculture is anchored around several recent digital innovations, such as cloud computing, big data analytics, blockchain, artificial intelligence, remote sensing, drones, robotics, online platforms, internet of things (IoT), mobile phones and other digital communication technologies. These tools are often integrated into platforms or systems that enable real-time intelligence to improve efficiency, reduce or mitigate risks and minimise transaction costs along agri-food value chains (Santos Valle and Kienzle, 2020).

Rather than focus on the underlying technologies, digital agriculture is better understood in terms of the broad solutions that it offers along the agri-food value chain. Again, there are numerous terms used to classify digital agricultural services, many of which overlap and depend on the context. In this paper, key digital agricultural services in Africa are classified into five broad categories, namely: advisory services and extension, financial access, farm tools, market intelligence and supply chain management. A description of these digital agricultural services, as well as some illustrative examples, is given in Table 1. In advanced agri-food systems, these services are often ubiquitous, spanning the entire value chain including input supply, on-farm production, post-harvest handling, agro-processing, retailing, consumer usage, and waste disposal. Note that while emphasis is placed on purpose-built digital agriculture services, there numerous other digital tools that farmers and other value chain actors have repurposed for agrifood systems, including social media platforms such as Facebook, YouTube, WhatsApp, Pinterest, etc.

Table 1. Classification of key digital agricultural services in Africa.

Category	Description	Examples
Advisory and extension	Cheaper and timely provision of advisory and extension services using electronic devices	Customised extensions services, market information systems, early warning tools for weather/climate advisory and pest/disease control, predictive analytics, etc.
Financial access	Use of digital technologies to deliver financial products and solutions (also known as fintech)	E-wallet, mobile payments, commitment savings systems, warehouse receipt systems, index-based insurance products, credit risk profiling, crowdfunding platforms, etc
Farm tools	Digital technologies that optimise production and management	Farm management software, precision agriculture tools, drones, robotics, remote sensing, shared economy for mechanisation, pay-as-you-go irrigation, internet of things etc.
Market linkage	Technologies that facilitate information sharing, enhance coordination, and minimise transaction costs across value chains	Online agri-inputs and output markets, service provider linkages, e-commerce, supply chain management, traceability solutions certification, traceability etc.

3. Growing recognition of digital agriculture in Africa

To contextualise the current status of digital agriculture in Africa, it is useful to review a brief history of this relatively new phenomenon through key milestones from the past decade. In 2011 the World Bank released a flagship report on "ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions", a resource designed to support practitioners, decision-makers, and development partners (World Bank 2011). The sourcebook consolidated interest on the intersection between ICT and agricultural development among academics and development practitioners alike. In 2013, the first ICT4Ag international conference was held in Rwanda co-hosted by the Technical Centre for Agricultural and Rural Cooperation (CTA), the Ministry of Agriculture & Animal Resources (MINAGRI), and the Ministry of Youth & ICT (MYICT). A sign of the growing interest, over 400 delegates from around Africa, the Caribbean, Pacific, and beyond gathered to discuss the latest initiatives in ICT for agriculture. In 2014 the Global Open Data for Agriculture and Nutrition (GODAN) was launched with an emphasis on collecting high quality data geo data, weather data and market data. In 2016, the ICT for Ag annual conference was inaugurated and has since then become an annual "convening that aims to bring together global audiences, engaging experts and enthusiasts who want to find solutions to bridge the food security gap and build resilient communities in low- and middle-income countries" (ICTforAg 2021).

For Africa, the year 2019 marks a significant milestone in which digital agriculture gained widespread recognition as a driver for agricultural transformation. The year started with agriculture ministers of 74 countries attending the 11th Berlin Agriculture Ministers' Conference to discuss how digitalisation can strengthen the agricultural sector's economic viability, sustainability, resource conservation, resilience and consumer orientation (Global Forum for Food and Agriculture 2019). The meeting culminated in the signing of a communique "Agriculture Goes Digital – Smart Solutions for Future Farming" by most ministers of agriculture from Africa. In the same year, two major reports were released that unpacked the potential of digital agriculture in Africa. First was the Malabo Montpellier panel report entitled "Byte by Byte: Policy Innovation for Transforming Africa's Food System with Digital Technologies" (Glatzel et al. 2019). The second key report, led by the Technical Centre for Agricultural and Rural Cooperation (CTA) and Dalberg Advisory, entitled "The Digitalization of African Agriculture Report, 2018-2019" gave a comprehensive assessment of this growing subsector (Tsan et al. 2019). In the same year, several governments and development partners made significant commitments to support digital agriculture initiatives. For example, the African Development Bank launched a flagship initiative on "Digital Solutions for Smallholder Agriculture". To cap the year, the theme of the African Green Revolution Forum (AGRF) forum, the biggest annual convening of agricultural practitioners on the continent, was "Grow Digital: Leveraging digital transformation to drive sustainable food systems in Africa". These high-level events

and key reports in the same year cemented the relevance of digital solutions in Africa's agri-food systems that continues to grow.

4. Driving forces – Africa's cell phone boom

The rapid adoption of digital agriculture services across Africa is part of a larger multi-sector transformation that has been dubbed the fourth industrial revolution (also known as 4IR or Industry 4.0). This revolution broadly refers to the rapid change of technology, industries, and societal patterns and processes due to increasing globalisation, interconnectivity and smart automation (Bai et al. 2020). While numerous factors have aligned to spur the digitalisation of agri-food systems across Africa, the primary driver has been the rapid mobile phone penetration.

Africa has experienced an unprecedented rapid rise in mobile phone usage over the last decade. As illustrated in Figure 1, mobile phone subscriptions in Africa grew from under 10 per 100 people in 2005 to more than 90 per 100 people by 2020 (World Bank 2022). Between 2010 and 2015 the number of mobile phone subscribers in Africa grew at a compounded annual rate of 11% compared to the global average of 8%. According to the latest GSMA report, the number of unique mobile subscribers[2] across Africa in 2020 was estimated at 495 million representing a penetration rate of 46% (GSMA 2021). About half (48%) of these connections are smartphones, which are projected to reach 64% by 2025 (GSMA 2021). The significant increase in use of smart phones widens the opportunity for more phone-based applications across all sectors especially health, education, finance, and agriculture.

The main factor behind the rise of mobile phones in Africa is that the continent was already lagging behind in telecommunications connectivity with limited fixed telephone line networks. Thus, the unprecedented growth in adoption of cellular phones is a classic case of technology leap-frogging (Fong 2009). The falling prices of mobile phones, especially secondhand devices, and the influx of international mobile service providers, have also resulted in more people owning and using mobile phones. For many Africans, the mobile phone is not just a communication device but also the primary channel to go online, as well as a vital tool to access various life-enhancing services.

Building on the rise in the use of mobile phones and the spread of internet access across Africa, investors are creating communities centred on tech development and execution. Tech hubs, which

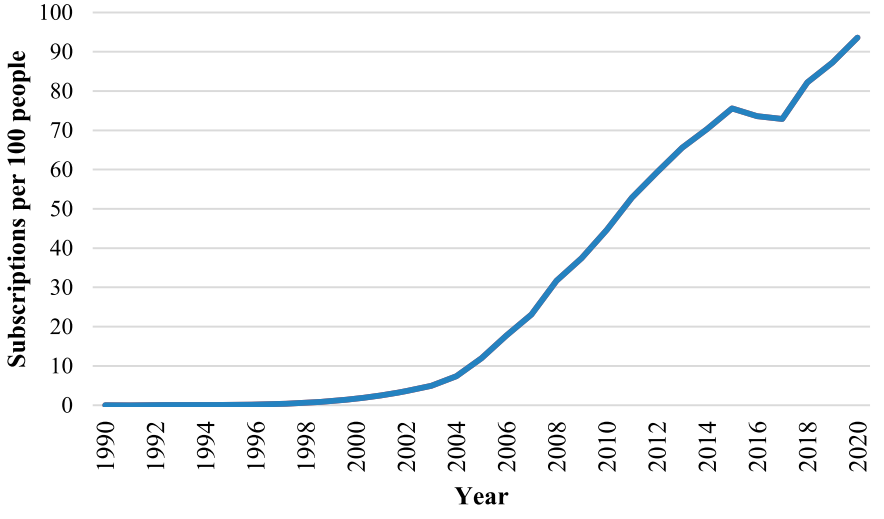

Figure 1. Mobile phone subscriptions per 100 people in Sub Saharan Africa (Source: World Bank Data, 2022).

the Global System for Mobile Communications (GSMA) defines as, "physical spaces designed to foster and support tech startups", have ballooned in number over the last several years (GSMA 2018). In 2016, the World Bank reported 120 tech hubs throughout Africa (Kelly and Firestone 2016). Based on GSMA statistics, the 2019 AfriLabs and Briter Bridges report shows 314 tech hubs across Africa in 2016; 442 in 2018; 618 in early 2019; and 643 in October 2019 with the larger concentrations in South Africa, Nigeria, Egypt, Kenya, Morocco, and Ghana (Afrilab and Briter Bridges. 2019). These centres are providing space for entrepreneurs from all sectors to innovate and integrate ICT into traditional sectors. It is these thriving tech hubs across the continent that have spawned numerous digital solutions to Africa's agri-food systems.

5. Status of digital agriculture in Africa

According to the CTA-Dalberg report, as of 2018, there were at least 390 ICT and digital solutions actively operating in the African agriculture space (Tsan et al. 2019). By the end of 2019, that number had gone up to 437 just for SSA (Phatty-Jobe, Seth, and Norton *2020)*. As shown in Figure 2, the number of digital agriculture solutions has skyrocketed from only 42 in 2012. These services reach an estimated 33 million agri-food value chain actors, most of whom are smallholder farmers. The top 15 digital agriculture services currently being deployed in Africa have over 22 million registered users, representing 70% of the total of number of active users (Tsan et al. 2019).

The CTA-Dalberg report classifies digital agriculture services into six thematic areas, namely (1) Advisory & information services, (2) Market linkage, (3) Financial access (4) Supply chain management, (5) Data intermediary and (6) Macro agri-intelligence. The supply (represented by proportion of primary use cases out of the 390 available solutions) and demand (represented by subscription services out of 33 million users) of each service across each of these six thematic areas is illustrated in Figure 3. Advisory and information services dominate digital agriculture in Africa with 35% of the available solutions and 68% of the subscribers. Eleven of the top 15 digital agriculture solutions primarily provide farmer advisory services (Tsan et al. 2019). Market linkage, which accounts for 27% of the available solutions, only serves 7% of the subscriptions. Digital financial services are experiencing significant growth in SSA driven by the rapid adoption of mobile money in many countries SSA (Phatty-Jobe, Seth, and Norton *2020)*.

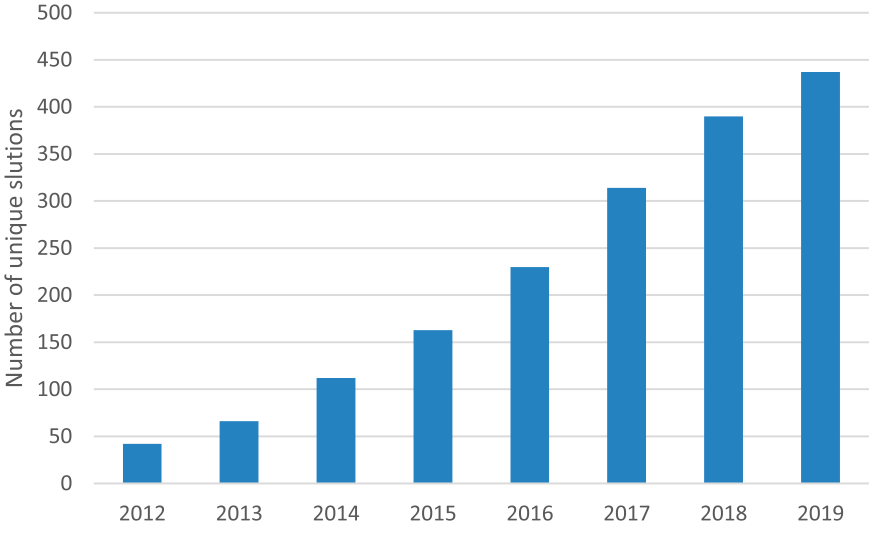

Figure 2. Number of digital agriculture solutions operating in Africa (Data Source: Tsan et al. 2019; Phatty-Jobe, Seth, and Norton 2020).

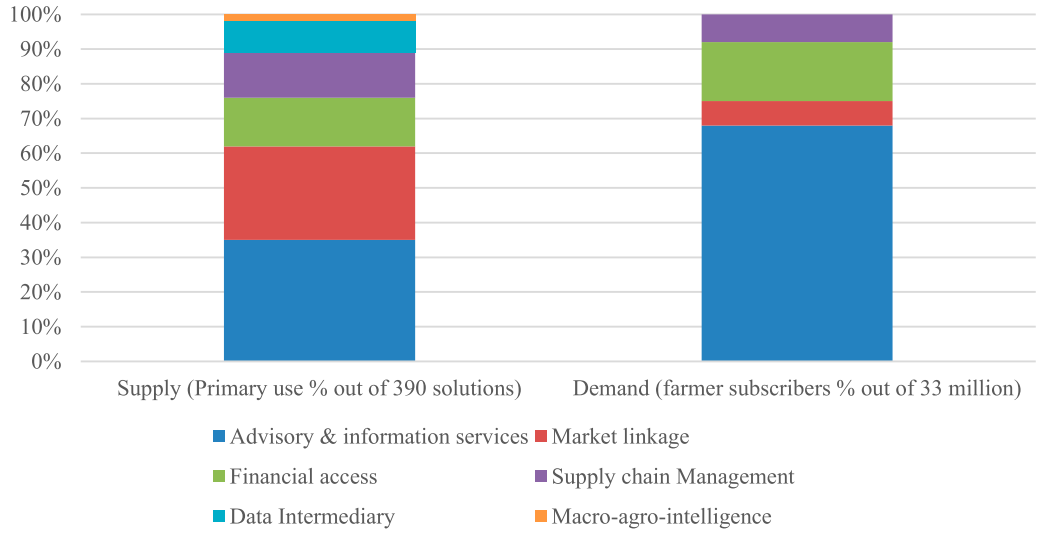

Figure 3. Supply and demand of digital agriculture solutions in Africa (Data Source: CTA-Dalberg).

Most of the digital agriculture solutions, about 74%, are provided by the private sector. NGOs deploy 16% of currently active digital agriculture solutions but only reach 6% of users. Mobile Network Operators (MNOs) and governments deploy an estimated 4% and 2%, respectively, of digital agriculture solutions. However, they have the largest user base, reaching 40% of the total users (Tsan et al. 2019). The statistics show the opportunity for governments to play a bigger role in deploying digital solutions for agriculture across Africa.

In terms of the geographical spread of digital agriculture, East Africa is most advanced and has the largest number of active users, an estimated 20.9 million,, compared to 5.1 million in Southern Africa, 3.7 million in West Africa, and less than a million in Central Africa. East Africa attracted USD 425 million worth of investments between 2015 and 2017, of which 64% was invested in Kenya, 26% in Uganda, 6% in Tanzania, and 3% in Rwanda (Krishnan 2018). Kenya alone has the highest digital agriculture concentration in Africa with 64 solutions headquarters in Kenya and 114 with a local presence (Tsan et al. 2019).

6. Digital agriculture in South Africa

Any analysis of South Africa's agricultural sector must be premised with an acknowledgement of its dualistic nature, i.e., smallholder versus commercial farmers. Smallholder farmers, comprising about 2.5 million households, face typical constraints that bedevil smallholder agriculture in many developing countries, including limited access to finance, lack of training, limited access to lucrative markets, climate change, high post-harvest losses, and low use of productivity enhancing technologies (Nwafor and van der Westhuizen 2020; Aliber and Cousins 2013). On the other hand, the commercial sector, comprising of about 35,000 large scale commercial farms, is highly diversified, export oriented, and fairly advanced with production systems that are on par with developed countries (Aliber and Cousins 2013). Most commercial farmers are early adopters of digital agriculture innovation, especially around precision digitised farm tools and precision farming. Smallholder farmers on the other hand are mostly limited to mobile phone applications due to budget constraints (Smidt, 2021).

A recently published Digital Agriculture Profile of South Africa provides a good overview of the status of digital agriculture solutions in the country (Born et al. 2021). The report shows a thriving and dynamic digital agriculture ecosystem characterised by many cutting-edge innovations (Born et al. 2021). These digital innovations are built on a solid power and communication infrastructure

Table 2. Key digital agriculture service and technology providers in South Africa.

Service area	Key providers
Online agronomy instruction	University of Stellenbosch in collaboration with AgriColleges, Agricultural Research Council
Precision farming	Aerobotics, University of Free State, Monsanto's Climate Field View, John Deere and Massey Ferguson tractors
Crowd farming	Impact farming, Livestock Wealth
Input service aggregation	Khula
Extension services	Agriculture Research Council, Connected Farmer, FarmRise, National Emergent Red Meat Producers
Market and input linkage	Farmer2Market, AgriProtein
Tracing and Certification	South African Organic Sector Organization

Source: Summarised from Born et al. 2021.

that currently provides 67% of rural inhabitants with electricity, 56% percent of resident with internet access, more than 100% mobile phone penetration rate, and 80% smartphone penetration (World Bank 2018; Born et al. 2021). However, South Africa's mobile data is prohibitively expensive with one gigabyte of data costing about US$10.37 (Alliance for Affordable Internet, 2018). This high cost, largely attributed to the government's delays in releasing new radio frequencies, remains a key impediment for smallholder farmers and agri-SMEs trying to access web-based digital agricultural services. That said, a wide variety of digital agricultural solutions are available to farmers and other agri-food value chain actors in South Africa. The key players providing digital agriculture services highlighted in South Africa's Digital Agriculture Profile are summarised in Table 2:

7. Impact on development outcomes – an evidence synthesis

Globally, numerous studies have been conducted to evaluate the impact of specific digital agriculture solutions. Most of the studies are highly specific to a single technology, value chain, desired outcome, country and time. As such it is difficult to give an overall assessment of the impact of digital agriculture given the very narrow scope of the evidence within most papers. To overcome this challenge, a systematic scoping review was conducted in 2021 to evaluate how farmers are using digital services in low – and middle-income countries (Porciello et al. 2021). A systematic scoping review is a study approach that seeks to "map the key concepts underpinning a research area and the main sources and types of evidence available" (Arksey and O'Malley 2005). The goal of the scoping review was to capture, classify, and annotate – to the fullest degree possible – the research on digital interventions in agriculture, using peer-reviewed studies and other carefully selected sources, in order to help funding organisations determine priorities for further programming and research. A full description of the project, featuring methods, presentations, publications and an interactive dataset is available online at https://agricultureinthedigitalage.org/.

More than 7,000 papers identifying digital agricultural services in Sub-Saharan Africa, Latin America and Asia were evaluated as part of this study, and a selection of 315 were included in the final assessment of how the proliferation of digital agricultural solutions impacts smallholder farmers. Research is clearly on the rise as the bulk of the studies, more than 50% were conducted within the last three years. In this section, we repurpose this scoping review to evaluate the evidence gap for digital agriculture research with an exclusive focus on the African continent. Out of 315 papers that meet the abstract screening for data extraction, 185 covered African countries. These studies cover 30 African countries as illustrated in Figure 4. The bulk of the studies are in the following five countries: Ethiopia (17), Ghana (24), Tanzania (23), and Uganda (28).

A summary of these 185 Africa-focused studies is presented as an evidence gap map in Table 3. On the vertical axis are types of digital agriculture services. The first column classifies the service types into four clusters, namely digital advisory and extension services, digital financial services, digitised farm tools and digital market linkages. For each cluster, the narrower service types are given in the second column. The horizontal axis shows the development outcomes resulting from the digital

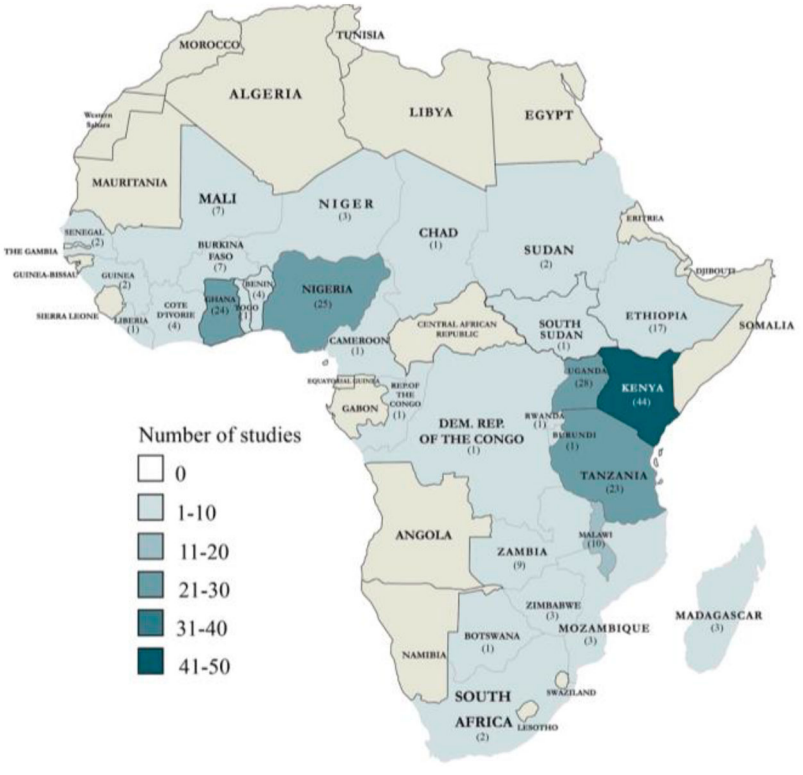

Figure 4. Coverage of studies on digital agriculture included in scoping review (author generated).

agriculture services. The first row classifies outcomes into four clusters, namely agricultural-led economic growth, resilience and risk, health, and gender, inclusivity and empowerment. The second row further breaks each cluster into more specific development outcomes. Four each outcome, the evidence of outcomes presented in the studies is classified into three columns: (1) nil, meaning no impact was found, (2) positive, meaning positive impact was established, and (3) mentioned, meaning that while the impact was mentioned in the paper, there was no clear quantitative evidence presented or the data interpretation was of low quality. The colour shading in the table highlights cells with a high concentration of studies. With a focus on Africa, four key conclusions from the evidence gap map are summarised below.

First, the literature with quantifiable evidence of digital agricultural services on livelihoods among smallholder farmers in Africa is still very thin. Across services there is a dearth of studies on digital finance, digitised farm tools, and market linkages. It is worth noting that two of three service types, finance and farm tools are relatively new and mostly provided by the private sector. As such, one possible explanation for the lack of studies is that data on these services is highly guarded as it considered to be strategic information by service providers. Across outcomes, the literature is thinnest on resilience and risk, a relatively new area of study. Moreover, measurements of risk and resilience are not clearly established. Priority areas for research in digital agriculture for Africa should include the following: impact on climate resilience and environmental sustainability, role of social and cultural barriers to equitable access, role of small and medium enterprises as service providers, and the value proposition of bundled services.

Second, the evidence gap map shows a large cluster of studies around digital advisory and extension services. Clearly e-extension is the hallmark of digital agriculture in Africa. Many African countries already had weak extensions services averaging more than 4000 farmers per extension

Table 3. Evidence gap map for digital agricultural services in Africa.

		Agriculture-led Economic Growth															Resilience and Risk									Health			Gender, Inclusivity & Empowerment														
		Income			Market Efficiency			Practice Change			Productivity			Yield			Climate Resilience			Cost Effectiveness			Resilience			Nutrition			Increased Knowledge			Social Inclusion			Social Learning			Gender					
Effect (0=nil, ÷=positive, *=mentioned)		0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*	0	÷	*
Digital Advisory & Extension Services	E-Extension	4	12	3	1	1	1		1	2	3	8	5	5	1	1	1		1	1	1		1	3	2	1	4	1	2	7	2	1	6	6	3	5	1	1	8	5			
	General Agronomy	3	12	6	1	1			1	1	1	1	5	5	16	5		2	1	1	2			2	2	2	3	3	5	1	4	1	7	5	4	9	5	2	11	4			
	Human Nutrition											1	1		1	1		1	1																	1	1						
	Markets and Prices	3	12	3	1	1	1		1	1	2	4	2	2	7	1		1	1					2	1						1		2	1	1	5	2		1	1			
	Livestock Information	2	6	5	1	1	1		1	1	2	4	2	2	7	1		1	1					2	1						1		2	1	1	5	2		1	1			
	Pest Management	2	3	2							1	1	1	2	2	2				1	1		1	1	1	2	2	1	1	1	1	1	1	1		1	1	1	2	2			
	Seeds and Fertilizer	2	5	3							2	3	1	2	3	1					1		1	1	1	1	1	1	3	5	2	1	1	1	2	2	1	2	3	2			
	Soil and Land	2	5	2							2	4	1	2	4	1							1	3	1	1	3	1	2	4	1	1	1	1		2	1	2	3	2			
	Water and Irrigation		3	1								3	1		3	1		1	1					2			3	1		3	1				1							
	Weather and Climate	1	5	1	1	1					1	5	2	1	7	1		1	2					1						1			2	1	1	4	1		2	2			
Digital Financial Services	Credit		1	2			1		1	1		1	2		1	1									1			1						1								
	Insurance		2	1								1			1															2	1											
	Payments		4	3					1	1		2	1		1	1																	1	3								
	Saving		1	1					1	1																																
Digitized Farm Tools	Precision Agronomy		2	1							1	4	2	1	4	1								2			2			2	1	1	1			1	1	1	1	1			
	Farm Mgmt Software					1			1																																	
Digital Market Linkages	Agricultural Inputs																																									
	Supply-chain Mgmt	1	2	1			1					1	1	1	1					1	2	1				1	2	1														

officer compared to the FAO's recommendation of one officer per 400 farmers (Tambo et al. 2019). Mobile phones have unlocked the ability to deliver real time advice to farmers in multimedia formats and in local languages. All this can be achieved at a small fraction of the cost of traditional extension services with the added convenience of round-the-clock availability within the comfort of your farm. Figure 3, presented earlier on the supply and demand of digital agricultural services across Africa, further supports the dominance of advisory and information services which account for 35% of the available solutions and 68% of the subscriptions.

Despite the limited number of studies, a bulk of the literature shows positive evidence of digital agriculture solutions on key development outcomes. For a few research areas, the evidence is solid. Supported by more than 10 studies, we can point to the following positive impacts of digital extension and advisory services: E-extension has a positive impact on farmer incomes; general agronomy has a positive impact on income, yield and gender; and market and price information has a positive effect on farmer incomes. Across the board, there is fair evidence to support that many of the digital advisory and extension services have a positive impact on income, productivity, yields, resilience, nutrition, social inclusion, social learning and gender outcomes. Against this evidence, governments, development partners, private sector and non-governmental organisations (NGOs) should double down on investments to increase content and access for digital extension and advisory services.

8. Opportunities and challenges

8.1 The COVID-19 crisis accelerates adoption

As discussed above, digital agriculture presents a unique opportunity to address key challenges in agri-food value chains across the continent. The subsector has grown tremendously over the past decade. As both mobile phones and internet connectivity become more affordable and ubiquitous, adoption of these technologies will likely accelerate and new innovations will emerge.

Perhaps the most significant opportunity for accelerating digital agriculture solutions has come from the COVID-19 pandemic. On the 11th of March 2020, the World Health Organization (WHO) declared the novel coronavirus (COVID-19) outbreak a global pandemic. The pandemic created an unprecedented global crisis that paralysed most economic sectors, including agri-food value chains. To curb the spread of the virus, many African countries imposed restrictions on human

movement across both domestic and international borders. Despite the best efforts to exempt agricultural value chains as essential services, the restrictions adversely impacted agri-food systems (Mukiibi 2020; Arndt et al. 2020). However, the restriction on human contact and crowd sizes resulted in rapid uptake of online services that minimised human contact.

One exception to the economic devastation from the pandemic is the ICT sector, which has seen a surge in demand for services (Almeida, Santos, and Monteiro 2020). Globally, COVID-19 has become "the great accelerator" for digitisation across social interactions, work patterns and business processes (Amankwah-Amoah et al. 2021). Take for example a comparison of the Rwandese economy before and after the pandemic. Every measure of the business environment including imports, exports, government expenditure, household expenditure and investments are down compared to pre-pandemic levels, and in most cases by double digits. The sector performance in quarter 2 of 2019 compared to the same quarter in 2020 indicated a 96% drop in air transport, 62% drop in hotels and restaurants, 67% drop in education, 53% drop in mining and quarry, 41% drop in trade, 20% drop in construction, and 13% drop in manufacturing (United Nations Development Program 2020). Only two sectors are up: health is up by 5% due to a rise in demand for medical products and services, and ICT is up by a staggering 33% (UNDP 2020).

While the COVID-19 pandemic has exacerbated Africa's food and nutritional insecurity (Mukiibi 2020; Khan et al. 2021), it has created a unique opportunity to accelerate the deployment of contact-free digital solutions along the agri-food value chain in most African countries (Fernando 2020). Governments have been forced to digitalise some of their agriculture services to curb the spread of the virus. Policy and regulatory reforms that would have taken years to implement have now been accelerated. To mitigate the effects of the pandemic on food production, in many African countries governments prioritised the provision of subsidised agriculture inputs to smallholder farmers, some of which were delivered through electronic vouchers. Thus, the pandemic has catalysed key digital agriculture solutions such as e-extension, mobile wallets, remote sensing, e-subsidies, e-commerce and online marketplaces (Oruma, Misra, and Fernandez-Sanz 2021; Fernando 2020). Many of these changes are likely to stay even in a post COVID-19 pandemic era.

8.2 Challenges: an infant industry still vulnerable to shocks

Despite the numerous opportunities presented by digital agriculture, there are some key challenges facing this subsector. First, it is important to note that while most digital services allow for contact fee transactions, they often require an analog setup involving human contact. A good example of this is farmer registration. Before governments and private sector can successfully deploy services to smallholder farmers, they need to go through a costly process of formally registering farmers with unique IDs on to databases. This process usually requires boots on the ground travelling in rural areas. These steps come with a high risk of virus transmission and were restricted at the peak of the pandemic. Consequently, such "onboarding" activities for digital agriculture solutions have been slowed down or postponed.

Another challenge, noted in the CTA-Dalberg report, is that most of the currently available digital agriculture solutions being deployed across Africa do not have a clear revenue model (Tsan et al. 2019). Many of the application are still funded or subsidised through donor initiatives. Moreover, the willingness to pay for services by smallholder farmer is still very low. Advertising revenues that have fuelled the growth of many digital applications are still very low especially for services that are targeting smallholder farmers with limited spending power. Until and unless digital agriculture service providers can develop revenue models to drive sustainability, the subsector is likely to shrink after the initial excitement wears off.

Every disruptive technology has winners and losers. Digital agriculture in not an exception. There is a growing concern about the "digital divide", defined as the growing gap between the underprivileged members of society, especially the poor, rural, elderly, and handicapped portion of the population who do not have access to information and communication technologies. In the case of many

African countries, there is evidence of significant and widening digital gaps between key segments of society. Access is much higher in urban areas compared to rural areas where most smallholder farmers reside (Mutula 2008). Evidence of the past twenty years shows that women are at a significant disadvantage compared to men when dealing with computers, smartphones and other digital technologies (Cooper 2006). Unless deliberate efforts are made to close these gaps, digital agriculture solutions have a risk of putting women at an even greater disadvantage. Similarly, most digital agriculture solutions favour literate and numerate users who have attained high levels of education. In some African countries with relatively low literacy, digital agriculture can also widen this gap unless deliberate efforts are made to be inclusive.

9. Conclusions and implications for agricultural economists

Digital agriculture innovations are a positive disrupter with the potential to improve efficiency across agri-food value chains. As mobile phones and internet access become more affordable and ubiquitous across Africa, adoption and subscriptions will continue to increase as old solutions are refined and new ones are introduced. The COVID-19 pandemic has accelerated the deployment and adoption of digital solutions driven by the growing need for contact-free services.

It is important to highlight that digital agriculture is an enabler not a solution the key productivity challenges underlying smallholder agriculture in Africa. As described earlier, the primary cause of this yield gap between Africa and the rest of the world can be attributed to limited use of productivity enhancing technologies such as irrigation, chemical fertilisers, agrochemicals, mechanisation and improve seed. While digital agriculture solutions might improve access to and affordability of these technologies, the scale and magnitude of the problem is much bigger. Thus, digital solutions might improve the efficiency and flow of information across the agricultural value chains, but they will not, by themselves close the yield gap. Parallel investments are needed to improve access to these productivity-enhancing technologies along with policy reforms that promote the creation and maintenance of an enabling environment. Moreover, significant investments from the government are required to support public infrastructure such as good roads and electricity.

The digital agriculture revolution presents some key lessons for our profession as agricultural economists. First, as highlighted in this paper, there are significant research gaps that are in urgent need of empirical inquiry. Researchers should take advantage of evidence gap maps to prioritise studies on under-researched topics in digital agriculture. More than ever before such research is needed to support evidence-based policies and regulations by governments as well as to set investment priorities by the private sector and development organisations. Many issues arising from digital agriculture innovations transcend academic disciplines. As such agricultural economists should collaborate across disciplines, including sociology, anthropology, engineering, information science, agronomy, etc. Finally, the era of big data is coming to our profession. Innovations in digital agriculture will generate new, high frequency and real-time data that can be harnessed to more accurately answer age-old questions. To take advantage of these opportunities, many agricultural economists will require retooling with new data managements skills such as big data analytics, artificial intelligence, and machine learning systems.

"There's a way to do it better – find it". Thomas A. Edison.

Notes

1. Note that there is a technical difference between "digitization" and "digitalization". *Digitization* is the process of converting analogue information to digital format (e.g., handwritten farm records being entered onto a database) while *digitalisation* refers to the use of digital technologies to enhance business operations.
2. Unique subscriptions rate is lower than count of mobile phone per 100 people because some people own more than one phone.

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