Digital Technology in Kenyan Agriculture: A Scoping Report

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ABSTRACT

Recent developments in Kenya's agriculture have seen a steady emergence of experimentations with a wide range of digital solutions targeting smallholder farmers. The inspirations driving these innovations and application of technology in the sector draw from the need to make agriculture efficient and cost effective and increase profits and food production, especially within the context of climatic change. Digital agriculture is being rapidly deployed in Kenya, with the promise of helping smallholder farmers for example, to improve and sustain yields, withstand unpredictable weather conditions and environmental degradation, and respond to market fluctuations. The application of digital solutions does not only involve farmers, but also auxiliary service providers such as agricultural input distributors, to resolve problems with product quality monitoring and traceability. There is some evidence that digital solutions in agriculture can improve efficiency by reducing financial and labour costs, informing management decisions, increasing product quality, reducing losses and using resources sparingly. However, digital agriculture can produce new inequalilties in data and knowledge ownership. Warning against romanticisation of digital agriculture, a political economy perspective requires attention to powerful actors and their interests. This review of a range of types of digital technologies points to the early dominance of several donor-funded initiatives partnering with local developers. Research should explore how smallholder farmers perceive and practically interact with the new digital knowledge on farming, and what explains various levels of uptake, and the outcomes for power and control in the agrofood system.

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1. INTRODUCTION

Recent developments in Kenya's agriculture have seen a steady emergence of experimentations with a wide range of digital solutions targeting smallholder farmers. The inspirations driving these innovations and application of technology in the sector draw from the need to make agriculture efficient and cost effective and increase profits and food production, especially within the context of climatic change. The integration of digital technology and innovation in agriculture is what is largely being referred to as digital agriculture (Klerkx et al. 2019). The technological services include solutions that use digital equipment and devices such as mobile phones, computers, satellites and sensors to solve various productivity and farm management challenges in agriculture (Keti et al 2021). Digital agriculture also encompasses the use of digital platforms e.g. databases and web portals (Han et al 2018).

Digital agriculture is reported to be helping in addressing some of the challenges faced by Kenyan smallholder farmers for example, lack of technology to improve and sustain yields (Fabregas et. al. 2019), unpredictable weather conditions and environmental degradation (Hart, 2022; Omulo and Kumeh, 2020; Mbandi, 2021; Deichmann et al. 2016). The application of digital solutions does not only involve farmers, but also the auxiliary service providers such as agricultural input distributors, who have also been facing substantial challenges like product quality monitoring and traceability (Baumuller et al, 2022; Limo, 2019). Many commentators agree that integrating digital solutions into agriculture can improve efficiency by reducing financial and labour costs (Munthali et al, 2022; Marinoudi et al, 2019), providing information to support management decisions (Borrero and Mariscal, 2022), increasing product quality and quantity (Fabregas et al., 2019), reducing losses and ensuring sustainable use of resources (Onyango et al., 2022). These researchers generally assert that digital agriculture can spur sustainable economic growth and development by addressing major constraints within the agricultural sector.

However, digital agriculture is not devoid of critique. McCampbell et al. (2022) argue that, despite their good intentions, digital technologies compromise many rights of smallholders in low-income countries, including the rights to data and knowledge ownership. Duncan et al. (2021) question the participatory justice in terms of how digital technologies reinforce knowledge inequalities that smallholder farmer around the world are already faced with. They argue that while there is clearly optimism about the potential of a "smart" farm economy, "there is an underlying uncertainty around who or what will be responsible for decision making and an ambiguity about how to characterize this while also championing the smart farm economy revolution" (Duncan et al., 2021:1194). Klerkx et al. (2019) caution that the new rules that accompany the development and use of digital solutions may lead to a reorientation of the division of labour in the agricultural food system leading to loss of jobs and livelihoods. Hackfort (2021) has also analyzed patterns of inequalities in digital agriculture. Finally, Mann and Iazzolino (2021) have documented how development aid funding for digital solutions in agriculture, recast corporate hegemony in Kenya, thereby shrinking the space for civil society. These and many critics warn about the over-*romanticisation* of digital agriculture as a 'fourth agrarian revolution' by asserting that the application of digital solutions may be counter-productive.

While digital agricultural technology is still evolving in Kenya, foundational technologies such as mobile and internet connectivity are already available to support innovative digital solutions to major challenges facing the agricultural sector. As part of the project â€“ Digital tech in African Agriculture, and based on a desktop review of both academic and non-academic literature, this report presents a synthesized description of the current landscape of digital agriculture in Kenya, including its key players across value chains, the main barriers they face, and the policy environment for regulating the adoption of those innovative digital solutions. In doing so, the report aims to avail background information that can go a long way in aiding the formulation of a larger research project to empirically explore the digital transformation in Kenya's agriculture. More specifically, this report addressed the following research questions:

1. What are the factors that drive the promotion of digital solutions in Kenya's agriculture?
2. Who are the actors involved in the promotion of digital solutions in Kenya's agriculture?
3. What digital solutions are being experimented or implemented in small-scale agriculture in Kenya and what are their impacts?
4. What are the challenges impeding the uptake of those digital solutions and what is responsible for their progress so far?
5. What policies and regulatory challenges and opportunities do those digital solutions face?
6. What research prospects emerge around these digital solutions that need further empirical analysis?

2. OVERVIEW OF AGRICULTURE SECTOR IN KENYA

Agriculture is considered the backbone of Kenya's economy because it plays an integral role in Kenya's economic performance. It is the largest contributor to the national GDP (30%) and is the main source of livelihood for most rural households. The sector employs more than 40% of the country's total active labour, including at least 70% of rural labour (Republic of Kenya, 2019a). Furthermore, the sector accounts for at least 65% of Kenya's export earnings (Wankuru et al, 2019). However, recent years have seen a drop in the economic strength of agriculture as national agricultural GDP growth rate has been in decline, from 10% in 2010 to only 2% in 2017. Despite the sector's substantial contribution to the national economy, Kenya's annual public expenditure on agriculture stands at below 5%, which is far below the African Union's target of at least 10% as established in the 'Malabo Declaration'. Kenya's agriculture is categorized into three types, small-scale, mid-size and large-scale (Table 1). The use of technology and mechanization amongst other parameters is often used as a distinguishing feature for these categories. Even within these categories, significant variation occurs in terms of use of technology. For example, commercial export horticulture tends to use more sophisticated information and communication technology (ICT) than large-scale maize producing farmers.

Table 1: Threshold for levels of agriculture in Kenya (Source: ASTGS, Republic of Kenya, 2019a)

Category	Small-scale	Mid-size	Large-scale
Farm size	0.5-5 ha	5-100ha	>100ha
Percent of share of farms	66%	20%	14%

3. CHALLENGES FACING SMALLHOLDER AGRICULTURE IN KENYA

The agriculture sector in Kenya is faced with many challenges that hinder its growth and limit its contribution to economic wellbeing of farmers and the country. These challenges range from governance to capacity and environmental conditions. In the following paragraphs, these challenges are elaborated.

Technological incapacity

Farmers in Kenya have limited access to modern technologies that can increase and sustain agricultural productivity. This is especially so amongst small-scale farmers. The government argues that Kenya is performing below its potential in agricultural mechanization rates (Republic of Kenya, 2019a). Financial constraints, especially amongst smallholders, are held to be largely responsible for the low mechanization. Consequently, rural smallholders prioritise their spending on pressing household needs such as food purchases, school fees and buying farm inputs such as labour and fertiliser, instead of investing in machines and equipment (FAO, 2020). Their financial constraints are further exacerbated by a lack of reasonable access to basic financial services, such as credit and loans (Parlasca et al., 2022). Most providers of loans require collateral and securities that smallholder fail to provide.

Limited access to information services

Informed decision-making by farmers is crucial in ensuring an increase and sustainability of yields. Yet information services to support decision-making are limited for smallholder farmers in Kenya (Okello et al. 2014). Information that is crucial for the smallholder farmer include weather forecast, market demand and prices, soil characteristics, pest incidence in the area, and so on. The majority of smallholder farmers make farm management decisions while relying on their experiences and indigenous knowledge (FAO, 2020). The indigenous knowledge and the many years of experience are increasingly becoming unreliable and are proving less effective amid volatile climate and environmental conditions (Shah, 2012).

Volatile weather conditions

A most pressing challenge for smallholder agriculture in Kenya is unreliable and inadequate rainfall, and occasional flooding in the lowlands (FAO, 2020). With only 7% of smallholder farmers practicing irrigated agriculture (Republic of Kenya, 2019a), rainfall is extremely important for smallholder agriculture. Increased climate volatility as an effect of climate change has thus substantially increased the risks associated with smallholder agriculture. These are evident in widespread crop losses as a result of increasing unreliable rainfall, long dry spells, frost, high temperatures, and frequent floods (FAO, 2020). These volatile climate conditions increase the already existing environmental degradation challenges, including loss of soil fertility and enhanced soil erosion.

Inadequate access to quality inputs

Faced with problems of volatile weather and environmental degradation, it has been argued that smallholder farmers need high-quality inputs to substantially improve yields, profits, and climate resilience, but cannot access them (Waithaka et al. 2007). Reasons include inadequate finance as farmers lack the capacity to take loans and credits (Chianu et al., 2008); poor road networks; and adulterated pesticides and fertilisers (Karingu and Ngugi 2013). Kenya's fertilizer application remains low at 33.6Kg/ha compared to the Abuja Fertilizer Declaration of 14 goal of 40 Kg/ha (FAO, 2020).

Difficulties in accessing stable markets

Whereas smallholders are semi-commercial producers, their attempts to participate in the much-touted agribusiness are curtailed by difficulties in accessing stable markets. Kenya's agricultural markets are mostly unstructured, characterized by significant price volatility, high transaction costs, small gross margins, and generally poor market access (FAO, 2020). Markets for most crops, such as fresh vegetables, maize, potatoes and fruits are controlled by brokers who act as intermediaries, and fix prices to the disadvantage of smallholders (Kamau, 2019). Postharvest storage and value-addition processing facilities are inaccessible to most smallholders. Poor road networks in some rural areas also make it difficult for smallholder to move their produce to the market in a timely manner (FAO, 2020). This leads to high postharvest losses and decreased product quality. As a mitigation measure, smallholders desperately sell their produce during harvest at low prices, while they could have stored and sold later when the prices rise. These challenges form part of the narrative that pushes for digitalisation of agriculture in Kenya.

4. WHO IS DRIVING DIGITAL AGRICULTURE IN KENYA?

Digital solutions in agriculture could potentially help smallholder farmers whose livelihoods are threatened by many structural and environmental challenges. These include need for financial inclusion, need to increase farmers' income through access to markets and the need to overcome the problems of climate change. These rationales ignite the expectation that smallholder farmers would demand digital solutions. On the contrary, though, digital solutions in Kenya's agriculture are not demand-driven (Bolwig et. al., 2021).

Research shows that the experimentation and expansion of digital agricultural solutions in developing countries draws great impetus from commercial activities of private firms (Birner et al., 2021), donor organizations and research institutions (Osiemo et al., 2021). There are at least 113 institutions supporting or offering various digital solutions in Kenya's agricultural sector, including corporations, donor institutions, government agencies, and small start-ups (FAO, 2020 and Osiemo et al. 2021). Birner (2021) identifies five firms that invest in the development and marketing of digital agricultural technologies and services in Kenya. They include large multinational agricultural input companies, large multinational and continental ICT companies; non-agricultural "hardware" companies, start-up companies innovating digital solutions; and agricultural processing and trading companies" (1269-70).

Multinational agricultural input companies

Companies which manufacture and/or supply inputs such as seeds, fertilizers, pesticides and herbicides to Kenya's farmers are mostly based in the US, Europe, China and India, and work through a wide network of dealers in Kenya. Their digital solutions enable supply and tracking of the inputs, which help reduce costs for the companies. "They build up their digital agricultural services by investing internally and by buying small software and hardware companies" (Birner, 2021:1269). They market their digital technologies and services through their networks of dealers. Multinational input companies driving the development and marketing of digital solutions in Kenya's agriculture include Bayer, Syngenta, Yara International, and Badische Anilin-und Sodafabrik (BASF). Some input companies have formed subsidiaries support research and development through non-profit third parties e.g. charities or development organizations. Bayer, through the Bayer Foundation, supports the development of digital solutions through the global organization Mercy Corps, which designed the Agrifin Digital Farmer (ADF) program to promote uptake of commercial farm inputs by smallholder farmers. Agrifin in turn created DigiFarm, supported by the infrastructure of Safaricom PLC and Arifu Chatbot for online learning. Through the Syngenta Foundation for Sustainable Agriculture, the multinational company, Syngenta, invests in various digital solutions that help connect its products and services with farmers. Farmforce has received support from Syngenta to create digital platforms for financial inclusion for the smallholders. Yara International manufactures and supplies products for plant nutrition and is one of the leading players in the fertilizer industry in Kenya. Yara Kenya supports 'smart faming solutions': CheckIT (a mobile App that allows possible identification of nutrient deficiency in plants), TankmixIT (a mobile App that avails information on how to mix various Yara fertilisers) and N-Tester (a hand-held nitrogen measurement tool).

Multinational and continental ICT companies

Large multinational software and big data companies like IBM, Microsoft, and SAP in the U.S. and Europe, TCS in India, and Tencent and Alibaba in China, invest in digital agricultural technology (Briner et al., 2021:1269). African-based telecommunication companies like Liquid Technologies have invested in digital agricultural solutions. Such investments are largely done in collaboration with development organizations, research institutions and governments. Microsoft for example has signed an agreement with the continental agricultural development organization AGRA (the Alliance for a Green Revolution in Africa), and the Kenyan government to accelerate the digitization of Kenya's agriculture. The collaboration explores the use of AgriBot as an e-extension solution.

Microsoft also has a start-up SunCulture with an Internet of Things (IoT) platform and Azure machine learning tools for their solar-based system, which allows them to offer farmers personalised recommendations through their mobile phones. In 2023, Microsoft has collaborated with OCP- Africa, an African-based fertilisers manufacturing company to scale-up OCP's digital agriculture platform that connects farmers to agriculture input and service providers. The partnership aims to use big data, machine learning and Artificial Intelligence (AI) to build OCP's data and AI platform to enhance operational efficiency and better serve the stakeholders in the ecosystem to support small-scale farmers. Microsoft goes beyond software design support, to funding policy research that can lead to an acceleration of the development, governance and uptake of digital solutions in agriculture.

IBM has been involved in agricultural digitalisation in Kenya since 2015, experimenting with its big data technology to support absentee farmers to monitor their farms digitally in remote areas. Through the Digital4Agriculture initiative implemented by Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ), IBM has offered IT expertise and digital weather infrastructure (The Weather Company) to a number of Kenyan start-up companies. IBM also supports blockchain machine learning technology in agricultural supply chain with Twiga Foods, the Watson Decision Platform for Agriculture which aimed to provide agriculture solution that combines predictive technology to give farmers insights about planning, ploughing, planting, spraying and harvesting. Multinational ICT companies are driving digital transformation agenda in Kenya's agriculture by providing ICT infrastructure that supports digital solutions are; Cisco, SAP and Google (Bolwig, 2021). Liquid Intelligent Technologies has also shown interest in the digital solution in Kenya's agriculture by collaborating with fresh produce companies, like Twiga Foods, to support IoT solutions. Another telecommunication company that drives the digital transformation in agriculture is Safaricom PLC, the largest telecommunication company in Kenya. Safaricom's widely-used M-Pesa service has been a major platform on which many start-ups anchor their digital solutions for inclusive financial services.

Nonagricultural "hardware" companies

A third driver of digital agriculture are non-agriculture hardware companies that manufacture and/or supply hardware components (Briner et al., 2021). These include companies manufacturing sensors, drones, and smart equipment. These include both foreign-based companies, which provide machines, machine connectivity systems and IoT hardware. For example a few companies are gaining entry into drones supply for many services including agriculture. For example, Flying Lab Kenya which is a subsidiary of WeRobotics incorporated in USA and Switzerland and which supplies DJI Agras and XAG drones from China; Astra Aerial Solutions, a Kenya-based company that assembles drones. With the expanding China-Kenya trade partnerships, we can expect that Chinese tech companies will become important actors in Kenya's digital agriculture solutions.

Other drivers of digital solutions in Kenya's agriculture

Several small start-up companies are involved in market-based solutions for digital agriculture, at the international, national and local levels - and typically with international investors. In Kenya, foreign-based start-ups largely come from the Netherlands, UK, US and Germany. Development organizations supporting start-ups include the World Bank, the African Development Bank, Consultative Group for International Agricultural Research (CGIAR), and UNFAO.

Other actors include the United States Agency for International Development (USAID), the Bill and Melinda Gates Foundation and Rockefeller Foundation from the US. The German Federal Ministry for Economic Cooperation and Development through GIZ supports digital transformation innovations and governance. Others include the Netherlands Development Organization (SNV), largely funded by the Dutch government. Kenyan universities are also under intense pressure from the public and government to demonstrate relevance in technology for agriculture. A number of them, with foreign funding, including from multinational tech companies, conduct experiments to provide scientific justification for agricultural digital solutions. The Kenyan government through the Ministry of Agriculture, Livestock, Fisheries and Co-operatives; Kenya Agriculture and Livestock Research Organization (KALRO); and Communications Authority of Kenya, provide a policy and regulatory environment aimed to enable digital solutions to thrive. These government agencies push the digital agriculture agenda through discourses of climate-smart agriculture, food security, youth employment, youth in agriculture, agribusiness and 'agri-preneurship'. For the government, the use of ICT technologies in agriculture in Kenya, offers good opportunities to convince a young generation of farmers in Kenya to make a living in farming instead of migrating to cities to look for unforthcoming jobs (Akuku et al. 2019).

5. SERVICES SUPPORTED BY DIGITAL TECHNOLOGY IN SMALL-SCALE AGRICULTURE

Osiemo and others analysed the services offered to farmers by 20 digital technologies in Kenya (Osiemo et al., 2021). They analyse the digital solutions along four services categories namely farm advisories, financial inclusion, creating market linkages and supply chain management (Figure 1). They observed that farm advisory is a key service that is supported by most (24%) of the digital technologies they analysed. These include weather forecast and agronomy extension services, data storage. Financial inclusion through services such as loans, credit and insurances against risks is the second most prevalent type of service offered by digital tech companies, accounting for 20% of the digital solutions analysed. These are evident in mobile payments and savings, access to credit, crowdfunding for investment projects, and digital credit assessment. Market access is also an important service for which farmers use digital technologies. These include information on market prices, access to input and output traders and markets. Digital technologies also provide support for supply chain management. These include product traceability and quality assurance, enterprise resource planning, and contract-farming scheme operation. Examples of digital solutions in Kenya's agriculture include:

- Mobile application
- Digitalized contracts and Blockchain
- Digital/automated weather stations
- Big Data technologies: cloud technologies
- Machine learning
- Artificial Intelligence
- Internet of Things (IoT): drones, sensors, cameras
- Satellite imagery

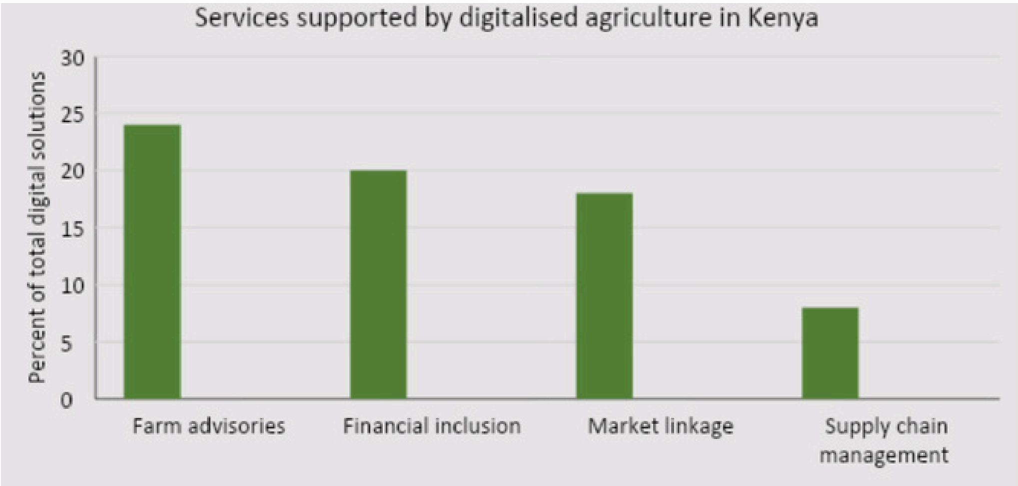

Figure 1: Agricultural services supported by digital tech in Kenya (Source, Osiemo et al. 2021)

5.1 Digital technologies used to support financial and market inclusion for farmers

This section presents a description of selected examples of digital solutions that have been developed and are being implemented in Kenya. More examples are presented in Table 2 in the Annex section. All of the examples are in pilot or formative stages. Information analysed has largely been sourced from the websites of the projects promoting those digital solutions.

DigiFarm

Safaricom PLC, in 2017, launched an integrated mobile-based platform called "DigiFarm", that leverages on big data technology to offer smallholder farmers a wide range of services related to market access, farm extension services, soil testing, and financing facilities such as crop insurance and credit for inputs (Parlasca *et al*., 2022). While initial design was to make use of big data technology, DigiFarm has evolved to incorporate other digital technologies, such as drones and IoT. The platform provides an interface of communication and financial exchanges between farmers and farm input suppliers, farmers and buyers of their produce, farmers and M-Pesa financial services. The interface connects four players namely, farmers, farm input vendors, M-Pesa and farm produce buyers. To operationalize the plan, farmers subscribe to the DigiFarm digital service by either signing into a mobile application or through an Unstructured Supplementary Service Data (USSD) code. They create their profile by providing specific personal information including the location of their farms, what crops they produce, the size of their farms, and estimated quantities of produce. Similarly, vendors create their profiles by providing personal data including name, location, name of the vendor's shop, farm inputs they sell and their prices. This information is stored and managed on an online database, known as FarmDrive. Once the farmer and the vendor are registered on the platform, they can connect.

The farmers can search for the inputs they need for their crop production, and choose among the input vendors, on the basis of the inputs they sell and their prices. If the farmer lacks enough finances to buy the inputs, they can apply for instant credits from Safaricom financial services, which is immediately credited to the farmer's M-pesa account. Loans are processed based on the farmer's credit profile supported by the data provided by the farmer on FarmDrive. That is, FarmDrive uses the data provided by farmers to automatically score their financing eligibility. This way, DigiFarm claims to make the farmers' financing efficient. However, the analysis of the marketing and promotional materials for DigiFarm reveals a reduced autonomy of the farmer as they can only redeem the loans for inputs and equipment at DigiFarm vendor outlets. Farmers can also take insurance with Safaricom's financial services against crop failure due to drought and pest infestation. To connect farmers to the market, buyers can search DigiFarm webpage for farm produce they want to buy, the farmers who sells the produce and the prices at which it is sold. Once satisfied, the buyers can place their order and make payment through Safaricom's M-Pesa services. This way, DigiFarm claims to eliminate middlemen and increase profit margins for farmers.

DigiFarm reports that at least 1.6 million farmers in Kenya producing different crops (especially fresh vegetables, maize and beans) have registered to use its services. These farmers are spread across 17 counties in Kenya. Of those who have signed up, at least 136,000 have been geotagged, implying the exact location and sizes of their farmers are mapped using drone-operated GPS. Further research is needed to determine any variance between those who have registered to use the service and those who actually use it. While farmers are able to access crucial services by using DigiFarm, what is apparent is that Safaricom uses the technology to expand the market base for its services. More empirical research is needed on the differential impacts of DigiFarm on both Safaricom, smallholders and other associated actors like registered and non-registered input suppliers, buyers, consumers and many more.

Apollo Agriculture

Apollo Agriculture is a Dutch start-up company founded in 2016 to offer mobile-phone based digital agronomy services to help farmers increase yields and reduce input costs. With support from Mastercard Foundation and other funders, Apollo Agriculture leverages on advances in machine learning, remote sensing, and mobile money services to deliver input financing and agronomic advice to smallholders. Since 2016, Apollo Agriculture has grown to register smallholder farmers for its services in Kenya. Apollo digital platform mediates provision of financing to smallholder farmers so that they can buy better farm inputs and equipment, increase their harvest, and turn their subsistence farming into commercial farming. Apollo's digital platform allows registered farmers to buy inputs with Apollo in cash or credit. They employ machine learning credit models to mediate access to credit applications and approval. Like DigiFarm, Apollo Agriculture requires farmers and input dealers (agro-dealers) to create a profile by submitting personal data to the platform including, name, location, size of the farm and crops planted (for the farmer) and name, location and inputs sold and their prices (for the agro-dealer). To develop farmers' data for credit profiles, Apollo Agriculture employs the use of high-resolution satellite imagery and machine learning. The data provided by the farmer helps the machine learning technology to verify credit eligibility of the farmer and calculate what amount they can get. Therefore, upon application for a loan to buy inputs by the farmer, Apollo digital platform provides an instant credit decision. Farmers who purchase inputs on Apollo's credit receive insurance to protect their investment from unexpected circumstances. Like in the case of DigiFarm, the autonomy of the smallholder is in question since the Apollo Agriculture dictates that credits must be redeemed at the agro-dealers registered on their digital store.

Apollo has registered more than 1,000 agro-dealers spread across various counties in Kenya to ensure maximum proximity to subscribed farmers. In addition to accessing credit financing, Apollo's machine learning mobile technology also allows farmers to receive agricultural training. The platform provides personalized recommendations on inputs such as seed varieties, fertilizers, pesticides, and irrigation based on soil and weather conditions. However, Apollo's technologies may be disrupting local farming knowledge that has been passed on from one generation to another. This critique requires further empirical analysis. Apollo reports on its website that by 2022, at least 70,000 farmers were active on its platform and that it had financed around 100,000 farmers. Farmers can interact with Apollo via a mobile App, Short Message Service (SMS) and USSD technology. Empirical research would help to elucidate how the benefits of Apollo Agriculture are distributed across the various actors, including the farmers.

FARMS Drought Coins

Financial and agricultural risk management for smallholders (FARMS) Drought Coins is a Blockchain technology run by a collaboration of Dutch organizations namely, ICS, Agrics, and EARS. ICS and Agrics collaborate work in East Africa to provide credit to farmers. EARS, on the other hand, is a remote sensing company that sells drought index-insurance in Africa (Sylvester, 2019). The farm data processed by EARS generates the creditworthiness of farmers that ICS and Agrics rely on to provide credits to farmers. FARMS Drought Coins leverages blockchain technology and satellite imaging to inform drought-indexed insurance to cushion farmers from climate-related risks. The companies aim to inspire easy entry into formal financial risk management for farmers and increase their financial literacy. The FARMS concept is enabled by a blockchain-based virtual currency platform called COIN22, integrated with remote sensing (satellite) data and mobile money solutions, which ensure transparent secure transactions and "earmarking" of funds, smart payment contracts and information dashboards (Sylvester, 2019). The FARMS scheme lets farmers grow into an insured state in three stages notably, exploring, gaining trust and fully covered. The exploration stage is the initial step taken by the farmer to join and register in the FARMS scheme. Farmers opens a mobile wallet by providing personal details, for example, land size, location, crops grown, average yield and household income. Farmers set aside money by buying virtual currency, "drought coins" or "drought vouchers", that are kept in their personal COIN22 mobile wallet account. The value of the coins mimic the local fiat currency at the ratio of one to one: one COIN22 is equivalent to one Kenyan Shilling.

Using this information and historic drought data, FARMS platform calculates the minimum amount of money the farmer could set aside in their mobile wallet each year in order to mitigate their risk. The suggestion is sent to farmers through an SMS. However, farmers are free to set aside any amount. At the end of the farming season, based on satellite drought data and the defined index, FARMS releases all or part of the amount to the farmer. The actual money flows into a farmer's bank account in real-time. This especially happens when the drought index is at least 20% lower than an average year (Sylvester, 2019). FARMS reports that amounts are released to mitigate risk, and that the amount of funds released increases with the intensity of the drought. Whereas the primary focus is drought, FARMS also designed Drought Coins to cover other risks such as reduced crop yield, due to pest infestation. However, the success of such an initiative will also depend on the trust that participating farmers have on the system. This can be hard to evaluate at these formative stages of the project.

5.2 Farm advisory and management services

FarmCloud and FarmShield

FarmCould and FarmShield are an integrated digital system that are operated by a Kenyan start-up company, Synnefa that began its business in 2013. The system leverages on internet cloud and big data technologies where farmers can store their digitized farm information. Participating farmers can turn their physical and analogue records into a digital inventory on Synnefa's FarmCloud. Hinging on the mantra of agribusiness, Synnefa reports that the inventory is useful for farmers in accessing financial credits for farm operations and improvement. Especially for export farmers, FarmCloud helps to provide traceable farm data that can be used to affirm compliance with regulations and certification for export market. To do this, farmers can generate reports, which are required by export companies as evidence of adherence required standards, and to process compliance certificates.

FarmCloud is integrated with FarmShield, an AI technology, which runs IoT equipment, especially solar-powered soil sensors that collect data for horticultural greenhouse farms and transmit these to FarmCloud for storage and processing. FarmShield combines solar powered digital sensors including NPK (nitrogen, phosphorus, potassium) nutrient sensors, soil moisture and soil temperature sensors, air temperature and air humidity sensors and light intensity sensor. It also connects to a water flow meter to monitor irrigation. All these are automated to perform the following decisions:

1. Opening and closing the irrigation system to let water flow into the farm if the soil moisture sensors report low soil moisture levels.
2. Activating greenhouse fans to evacuate humidity in the greenhouse if the air humidity sensors report high humidity levels.
3. Opening and closing of the greenhouse side ventilation if the air temperature sensor reports high temperature levels.
4. Timely alerts on low or high levels of nitrogen, phosphorus and potassium in the soil.

Using a mobile phone App, web portal or USSD, farmers can use the services of FarmShield to control their farms remotely from their mobile phones and dashboard while getting real-time information on nutrients and water needs for their crops. Data from the farm is sent by FarmShield to FarmCloud where it is stored. FarmCloud analytics technology is used to analyse and display data on a dashboard which farmers interact with to make informed decisions. Farmers can also use the dashboard of FarmCloud place orders for farm inputs, ordering trucks to collect farmers' harvests, raise invoices for payment by their customers.

Twiga Foods and Liquid Intelligence Technologies

Twiga Foods, an agri-tech company, is a major actor in food system in Kenya. Initially, Twiga leverages on ICT to enhance food distribution in Kenya, especially for the urban population. Since 2020, it has partnered with Liquid Intelligence Technologies, a to support the use of IoT technologies in a 650ha farm (Takuwa farm) in southwestern Kenya to produce tomatoes, onions, water melons and other fresh produce. The system includes four different types of agriculture sensors: a comprehensive weather station, soil moisture and temperature probes, borehole water meters, and sensors for measuring irrigation water acidity and salinity. The system takes advantage of Liquid Intelligence Technologies' extensive low-power and wide area network in Kenya.

The soil sensors installed at Twiga's Takuwa farm measures moisture levels and temperature at six different depths in the soil, giving precise information of soil quality and irrigation needs at the roots of specific crops. The objective is to increase yield and productivity with a trickle effect on food security. The sensors provide critical information to the Twiga agronomy team. The smart weather station provides real time data that helps farm managers deploy the most effective farming methods for irrigation and application of pesticides. The water quality sensors provide specific metrics that help the Twiga team to optimize their fertilizer application. Additional data is gathered and monitored on a real-time basis including temperature, humidity, rainfall and wind speed, which are essential in the various aspects of Twiga's crop production.

In an interview with a Kenyan media, Twiga Foods reported that since the IoT deployment, its Takuwa farm has increased farm production due to more precise application of inputs and faster reaction times to local weather and soil conditions. By applying inputs based on data received on hyper-local weather and soil and water content, Takuwa farm can also save on costs related to irrigation water/pumping, fertilizer, and pesticides. The use of soil probes in monitoring the soil moisture in the expansive farm has resulted in an efficient use of water, as irrigation is only done when the soil moisture level is low. Liquid Intelligence Technologies in its website estimates that applying the technology has helped Twiga Foods to save 30% of irrigation water, and increased crop yields up to 25%. Worker hours on irrigation are also reported to have reduced by 50%. Our analysis of these reported outcomes indicate that they are aimed at justifying the potential of the digital solutions to cut cost of production and increase profits for the company. Following these outcomes, Twiga is set to expand its farming operations on the 20,000 acres of government-owned Galana Kulalu irrigated farming project. The case of Twiga Foods is relevant to understanding how digital solutions might power private sector hegemony over food systems where smallholders are important players.

Use of drone technology

While highly restricted by aviation laws, the use of drones in Kenya's agriculture is under experimentation to enhance precision in farming. Astral Aerial Solutions, a company affiliated to Astral Aviation Company that operates cargo flights, is one of the leading actors promoting drone technology in Kenya. The largest market and target for drone technology is the large-scale farmers. Examples include Unilever (sunflower), Del Monte (fresh fruits), Twiga Farms (fresh vegetables) and many others. These companies leverage drone technology to produce maps that are needed to successfully identify farm variations such as gaps among crop rows and bushes, and identify areas with irregular water supply. Drones also provide topographical information that enables structural planning within the farms, land tenure management by knowing boundaries, and near real-time records of farm performance.

Crop spraying is another application of drone technology, which remains highly controversial in terms of impacts on labour and employment. Aerial crop spraying by drones changes farm labour relations by offering cost savings on the application of farm inputs with increased safety, effectiveness and flexibility, regardless of the terrain or ground conditions. It also improves precision in spraying process, ensuring that all areas are effectively covered. Safaricom, whose DigiFarm technology promotes drone services for agriculture, reports that drone spraying can save costs for the Kenyan farmer in two major ways. One, drones save the amount of chemicals needed for spraying by 60% compared to hand spraying. In their view, this reduces the quantity and therefore cost of pesticides. Two, they claim that drone spraying saves labour costs significantly.

Another example of where drones are used in smallholder agriculture is the Third Eye flying sensors (drones combined with IoT) project implemented by Future Waters, a Dutch-based development consulting company with projects in both Kenya and Mozambique. The development and implementation of ThirdEye is funded by United States Agency for International Development (USAID), Swedish International Development Agency (SIDA) and the Netherlands Ministry of Foreign Affairs. Future Waters works on the premise that smallholders have limited resources (seed, water, fertilizer, pesticides, human power) and lack the information that can enable them allocate their limited resources efficiently in a spatiotemporal context. Through the ThirdEye project, Future Waters uses drones fitted with sensors to collect spatial information and provide this to farmers to inform their decision-making. As part of Smart Water for Agriculture program implemented by the Dutch global development agency SNV, ThirdEye has set up a network of flying sensor operators, equipped with flying sensors and tools to analyze the obtained imagery.

Flying sensors also offer the opportunity to obtain information outside the visible range and can therefore detect information hidden from the human eye â€" hence the name Third Eye. For example, ThirdEye explains that sensors use the infra-red spectrum to detect crop stress about two weeks before the human eye can see this, by magnifying the reflection of unhealthy crop leaves. By measuring the reflection in these spectra, damaged plant material can be distinguished from healthy plant material, that would otherwise be hidden to the human eye. The innovation is reportedly transforming farmers' decision making regarding the allocation of limited resources such as water, seeds, fertilizer and labor. That is, instead of relying on common-sense management, farmers can rely on the innovation to take decisions based on data, resulting in an increase in water productivity. The flying sensor information helps farmers to see when and where they should apply their limited resources. With information from flying sensors, smallholders can also manage their inputs to maximize yields, and simultaneously reduce unnecessary waste of resources. ThirdEye project reports on its website that by 2017, there were 2,000 smallholders using its services. Since it introduces a new way of knowing plant health, further research should investigate what happens to the previous ways of knowing the health of plants by smallholders.Research could intererogate the question: Do farmers lose this traditional knowledge based on their farming practices and experience, or integrate them into ThirdEye technologies?

Large-scale farmers also use drone services to provide crop inspection data to add a layer of efficiency and effectiveness to pest management. Drones collect data that is used to produce crop health maps that give the geo-location of hotspot areas exhibiting specific physical and health variabilities. This reduces the time and effort in farm scouting and collecting soil samples. As with several other technologies, while these savings on labour look appealing to the large-scale farmer, they may lead to job losses, with long-term consequences for household economies and national employment rates. These dynamics needs to be considered in the evaluation of the success or failures of the technology for a nuanced understanding of their roles in shaping labour relations in the agricultural sector.

Kenya Agricultural Observatory Platform (KAOP)

KAOP is a government-run integrated online platform that uses geo-data from satellites to generate real-time and location-specific agro-advisories to farmers and other stakeholders. It is implemented as part of the Kenya Climate-Smart Agriculture Program financed by the World Bank through the Ministry of Agriculture, Livestock, Fisheries and Irrigation. The system is able to predict precipitation and temperature, for any location in the country, for the next fourteen days, and provides weather observations for the past 7-10 days. The data is used to generate agronomic advisories for farmers at ward levels. Farmers can access the advisories through a KAOP web portal and/or SMS.

The government has not reported the number of farmers who access and use the services. It also remains unclear whether or not farmers engaged in mixed cropping find the platform useful. Other critical matters to consider the range of inputs it promotes, and whether the platform may exclude farmers who grow local seeds saved from previous harvests as opposed to hybrid seeds purchased from local agro-dealers â€“ or whether it promotes the uptake of bought inputs (Almekinders et al. 2021, Hebinck and Kiaka, in press).

6. FACTORS SLOWING DOWN UPTAKE OF DIGITAL AGRICULTURE IN KENYA

A combination of many factors impedes the uptake of digital technologies in Kenya's agriculture, especially among smallholders. Kieti et al. (2022) have analysed various impediments to the uptake of smart technologies in this sector.

The first challenge is the limited digital infrastructure. Whereas important gains have been made in establishing digital infrastructure in Kenya, a number of areas in the country still lack mobile phone connectivity and broadband internet service (FAO, 2020). This is especially so in rural Kenya where most of smallholder agriculture is practiced. Access to the internet in rural Kenya was as slow as 13% of total adult population by 2019 (KNBS, 2020). Even for those in coverage areas, connectivity subscriptions and technology devices often remain out of reach financially. For example, whereas there were over 63 million mobile phone subscribers in the country, only 17 million had access to the internet (Osiemo et al., 2021). While some of the digital services can be accessed via USSD code or through SMS, better access is through mobile apps and web portals that require internet connections. In their study, Kieti et al. (2022) report that whereas large-scale farmers can afford smartphones, most smallholders in Kenya can only afford basic feature phones. This is a glaring inequality in terms of access to digital services in agriculture.

A second barrier to large-scale adoption relates to the human capacity to handle digital transformation. Digital literacy directly affects how the technologies are used by farmers (Lewa and Ndungu, 2012). Many studies (Lewa and Ndungu, 2012; Morwani et al. 2017; Kimaru-Muchai et al, 2012) show that more than half of smallholders in rural Kenya have no college education. Smallholders are considered to be lacking operational digital skills in using smartphones even when they can afford such devices (Kieti et al. 2022). Consequently, usage of innovative features beyond SMS, amongst farmers, remains minimal amongst smallholders (FAO, 2020). Moreover, there are only a small number of back-end-professionals who can proficiently use and maintain most of the digital solutions for data management, blockchain, machine learning, IoT, GIS, and drones (Osiemo, 2021; Bolwig et al. 2021). Design and maintenance services for digital solutions are thus largely handled by multinational ICT companies in their source countries.

Many digital solutions or technologies remain unknown to most farmers, limiting their scale-up. Kieti et al. (2022) attribute the low discoverability of digital solutions to ineffectiveness among the awareness creation channels used and the absence of collaboration among players in the digital agriculture ecosystem. Even in situations where farmers are likely to own and use smartphones, they remain largely unaware about the opportunity to use digital agricultural solutions that might be in the market (Bolwig et al., 2021). Some marketing platforms including agricultural expos might be impactful, but remain largely inaccessible to smallholders due to exorbitant costs for access. Affordability of digital solutions and their value proposition is an important factor slowing down the uptake of the technologies in agriculture (Wyche and Steinfield, 2016). Most of the technologies require subscriptions or payment to access. Many smallholders find the charges for data connectivity to access digital solutions expensive, including the cost of buying a smartphone (Kieti et al. 2021), and paying subscriptions fees for digital services.

Subscriptions to access data ignites the political discussion on the role of the government in ensuring open access to essential agricultural data and information. Kieti et al. (2021), for example document that their respondents suggested open access to services instead of paying to get the services created from the data farmers provide. Moreover, whether or the use of these digital solutions can deliver economic returns to offset their costs is yet to be fully empirically evaluated. If the economic returns do not offset the costs of farming for smallholders, then farmers are likely to be slow at on-boarding. Instead, they will continue to rely on other less costly ways of making decision, including through indigenous knowledge.

Bolwig et al. (2021)) argue on the basis of their study that many apps and ICT projects for agriculture fail to pick up and deliver real change because they are not demand driven. The digital solutions are developed based on a technology-push approach rather than an analysis of latent demand. They observe that more often than not, digital solutions in agriculture are developed by ICT firms without involving users in the innovation process, nor do they understand the social and economic context in which their technology would be applied.

7. FACTORS RESPONSIBLE FOR THE PROGRESS IN DIGITALIZED AGRICULTURE

Despite the many challenges that hinder the uptake of digital solutions in Kenya's agriculture, there has been considerable progress. Many projects are at their pilot stages, and each year new ones join the stage of experimentations. A number of factors could explain the progress so far seen in the digital solutions in agriculture. First, the rapid uptake of mobile technology in Kenya such as mobile payments systems e.g. M-Pesa and Airtel Money, are an indication of how technology can be disruptive and reach millions of people (Akuku et al., 2019). M-Pesa services have especially had a euphoric effect on the potential of home-grown ICT for development that many of these innovations ride on. That Kenya houses a leading mobile phone money service in Africa (with at least 50 million subscribers), is a demonstration that Kenya is an important market for ICT and digital solutions in Africa. This partly inspires a second factor for progress which relates to the mushrooming of multinational ICT companies in Kenya. Nairobi has a regional hub for innovations into ICT and cyber technologies as many multinational ICT companies establish their regional headquarters in the city. They influence the emergence of many start-ups founded by Kenyan ICT professionals, some of whom are living in the diaspora. A third factor relates to the restructuring of donor funding to development through trade and business partnerships. This approach to development aid is favoured by the right-wing governments that have been on the rise in traditional donor countries including those in in Europe. The Netherlands for example has been keen on fostering trade through aid in Kenya, including commissioning a study that explores opportunities for Dutch ICT companies in engaging in Kenya's food production through agriculture (Akuku et al, 2019). Aid is increasingly being tied to trade partnerships (Pettersson and Johansson, 2013), providing business niches in aid recipient countries for technology companies from donor countries. These are often coined as technological capacity building for developing countries to overcome their challenges including food insecurity and climate change. Notable example in Kenya include the Digital Transformation Centre funded by Germany's BMZ and the EU; Kenya's Climate Smart Agriculture Program funded by the World Bank Group; and Green Data Centres, also funded by the World Bank.

8. DATA GOVERNANCE, POLICIES AND REGULATORY ENVIRONMENT IN KENYA

One of the most important stumbling blocks towards digitalization of agriculture in Africa is the political question of data ownership and justice. Agricultural data contain personal information like name of farmers, mobile phone number, GIS location of the farm or agro dealer, which are clearly personal data that warrant privacy, protection and security. The question of how farmers' face the risk and vulnerability of losing ownership of the data they supply to data handlers, therefore becomes fundamental (Osiemo et al., 2021; FAO, 2020). The question calls for a robust regulation of data in terms of how it is obtained from farmers, how it is handled, processed, stored and used. Article 319(c) of Kenya's Constitution asserts the right to privacy (Republic of Kenya, 2010), which has a direct bearing on the collection, processing and use of personal data. Compared to other sub-Saharan African states, Kenya has vibrant and robust legal and policy environment to ensure digital data governance. However, the policy documents and legal instruments are relatively new and largely unknown to many data owners and handlers. Nonetheless, the documents, if implemented promises a robust policy and regulatory environment for governing data produced, handled and processed as digitalization of agriculture takes root in the country. The most important legislative document governing the usage of farmers' data in Kenya is the Data Protection Act (DPA) of 2019 (Republic of Kenya, 2019b).

8.1 The Data Protection Act

The Data Protection Act (DPA) was passed by parliament in November 2019 to regulate the processing of personal, data and the protection of data subjects' privacy rights. Section 25 of the DPA stresses that every data controller or processor (i.e., agro-dealers, government agencies, and any other actors collecting and processing farmers' data) must ensure adherence to eight data protection principles. These are:

Adherence to the right of the data subject (the farmer) to privacy.
Ensuring lawfulness, fairness and transparency in collecting, handling processing and using data.
Processing personal data for explicit, specified and legitimate purposes
Ensuring that personal data is adequate, relevant and limited to what is necessary for data processing purposes.
Providing the data subject with valid explanation whenever information relating to family or private affairs is required.
Ensuring that personal data is up to date and taking reasonable steps to ensure that any inaccuracy is erased or rectified without delay.
Ensuring that personal data is not kept for periods longer than the purposes it was collected for.
Ensuring that personal data is not transferred outside Kenya unless there is proof of adequate data protection safeguards or consent from the data subject (Republic of Kenya, 2019b).

DPA is critical in digitalization of agriculture because it regulates processing of famers personal data, provides for the rights of farmers as data subjects and sets out legal obligations and responsibilities for data controllers and processors. In addition, DPA provides for the establishment of the Office of the Data Protection Commissioner (ODPC) as the enforcement body of the provisions of law. Therefore, all farmers data collection and processing policies and guidelines are legislated and regulated by the DAP and governed by the ODPC.

8.2 Agricultural Sector Transformation and Growth Strategy (ASTGS)

The government of Kenya has formulated a 10-year Agricultural Sector Transformation and Growth Strategy 2019-2029 (ASTGS) to create a vibrant, commercial, and modern agricultural sector that supports 100% food security in the context of devolution (Republic of Kenya 2019a). ASTGS emphasizes the role of data and digital solutions in enabling the anticipated agricultural transformation. In particular, ASTGS's second anchor focuses on "strengthening research and innovation, and launching digital and data use cases for better decision-making and performance management" (Republic of Kenya, 2019a). The strategy emphasizes the multiplier effect that digitalization and data analytics can introduce to the agricultural sector. This has the potential to improve the scale and utility of agriculture performance assessments. The opportunity for data to transform value chains means that such aspirations must be actioned with due consideration of data subjects' and users' rights (Strathmore University and Microsoft, unpublished). ASTGS therefore calls for the development of a national framework to regulate and facilitate data exchanges and wide-scale analytics so as to integrate the decentralised operations of Kenyan data handlers relevant to agriculture. The result has been the formulation of the Farmers' Data Governance Framework.

8.3 Farmers' data governance framework

The Ministry of Agriculture, Livestock, Fisheries and Irrigation has developed an elaborate and robust data governance framework (Republic of Kenya, 2022), to guide decision making on the collection and use of data provided by farmers. The framework is aimed at ensuring a transparent and rights-based governance processes for the farmers' data. The framework outlines data categories and types which require lawful and procedural decision-making processes. It further outlines five pillars that underline data governance processes. The first pillar focuses on roles and responsibilities of data stewards, data managers and editors, data handlers and data experts. These roles and responsibilities require that farmers' data is accurately collected, turned into interoperable quality data sets, and processed and accessed in compliance with relevant laws. Accordingly, the framework is very elaborate on the roles and responsibilities of the various data handlers. A steering body is also identified accordingly to ensure that the roles and responsibilities are complied with. Secondly, the framework outlines the privacy standards that needs to be adhered to while collecting, storing and processing farmers' data. Here the framework gives autonomy to the farmers as the owners of the data by determining what is considered personal and non-personal data and how these need to be handled and processed including; obtaining farmers' informed consent, complying with farmers' rights, reporting breach of rights, and practices for upholding data privacy and security. The third pillar outlines the data protection and security guidelines including, data retention policies. The fourth pillar provides a set of data governance tools that data handlers and stewards can use in the implementation of the set policies and standards. The framework assigns ownership to the tools and a steering body to monitor and evaluate their usefulness and challenges. The fifth pillar outlines processes and procedures of handling farmers' data in a transparent and responsible ways at all levels. The levels include the collection, processing, documentation, sharing, and dissemination of personal data.

The framework clearly elaborates the processes and standards which need to be installed. The framework further requires that all stakeholders acting as data controllers, data processors, or third-party users have to be informed about the processes and standards. Finally, and importantly, the framework details a roadmap to operationalize the data governance framework. The roadmap underscores ten actions that should sequentially be taken to make the framework actionable. Nevertheless, the key to the success of the framework will be the collaboration between government (both national and county governments) and the private sectors, the deployment of adequate resources to carry out the actions in the roadmap and political will. One way in which this collaboration can be fostered in policy is the establishment of a data sharing platform.

8.4 Kenya Agricultural Data Sharing Platform

In order to integrate farmers' data and make the information as a public good, the government of Kenya through the Ministry of Agriculture, Livestock Fisheries and Co-operatives has established a data sharing platform â€" the Kenya Agricultural Data Sharing Platform (KADP). The ministry is the controller of KADP and requires all agricultural data handlers to upload the data on the platform in a timely manner. KADP is meant to revolutionize data exchange in agriculture by fostering collaboration between organizations and harnessing the power of collective data. By enabling seamless data sharing, the platform helps to build trust among organizations handling farmers' data. The platform consolidates fragmented data, standardizes data, and aids in better data categorization, enhancing its usability and value. Since the platform is a relatively new development, its use and impact in management of farmers' data is yet to be evaluated. This could be among the areas to focus on in future research.

8.5 Computer Misuse and Cybercrime Act

While Kenya has a robust policy and regulatory frameworks to govern digital agriculture, these documents are relatively new and largely unknown to many farmers and data handlers. For this reason, issues of data ownership and security remain a major fear for many users of digital solutions (Oseimo et al., 2021; FAO, 2020). These fears are largely affecting services where monetary transactions are involved. In 2018, Kenya passed the Computer Misuse and Cybercrime Act (CMCA), which is a law that provides offences relating to computer systems to enable timely and effective detections, prohibition, prevention, response, investigations and prosecution of cybercrimes (Republic of Kenya, 2018). The objectives of the CMCA have direct bearing on the collection, processing and use of data in digitalized agriculture, which rely more on computer and computing technologies. Firstly, the law intends to protect the confidentiality, integrity and availability of computer systems programs and data. Secondly, CMCA aims to prevent unlawful use of computer systems including acquisition of data. Thirdly, the law facilitates how unlawful use of computer systems, including data, can be investigated and punished. It also aims to protect the rights of privacy in computers systems and by extension through the personal data collected. Amongst the many offences that the law outlines are forgery and fraud. This speaks to the fears of many farmers who might worry about losing money through fraudulent payments, including accidental payments. For example, Section 35 of the CMCA makes it illegal for individuals to withdraw or withhold money accidentally sent to them without reversing to the sender within prescribed time. Even with the robust CMCA (Republic of Kenya, 2018), cybercrime seems to be worsening as Kenya now ranks as the third most targeted country for cybercriminals in Africa, trailing behind Nigeria and South Africa. Cyber security is a growing threat to digitalization of services in Kenya. The Communications Authority of Kenya reported 7.7 million cyber threats in 2017, 10.2 million in 2018, 320 million in 2021 and 860 million in 2023. This worrying trend underscores the need for heightened cybersecurity measures to enhance trust in the digital transformation in agricultural sector.

8.6 Policies on open data access

Several institutions including the UN-FAO have advocated for an enabling policy and regulatory environment for open data access in agriculture (FAO, 2020). They assert that publicly available data, particularly through government data platforms, can greatly enhance the digital transformation of agriculture and thus improve food security. Article 35 of the Constitution of Kenya establishes the regulatory framework for open access to data (Republic of Kenya, 2010). To operationalize this constitutional provision, Parliament passed the Access to Information Act (AIA) to concretely regulate open data access (Republic of Kenya, 2016). Consequently, through Kenya Open Data Initiative (KODI), the government has established the Kenya Open Data (KOD) portal.

9. CONCLUSION

Digital solutions in agriculture are significant aspects of the current agricultural transformation in policy, financing and practice. These solutions are still largely in their experimental stages and uptake is especially slow and low amongst smallholders. Discourses of food security (Onyango et al., 2022), climate change resilience (Meza et al., 2008; Cavazza, 2018; Barasa et al, 2021), youth employment (Akuku et al. 2019) and financial inclusion (Schachter, 2019), take centrestage in the case for digitalization in agriculture. Considering the significance of agriculture in Kenya's economy, digitalization emerges with the promise of revolutionizing the sector to higher productivity in the context of scarce resources and unfavorable environmental conditions (Mbandi, 2021; Onyango et al., 2022). Digitalization promises a new modernity in food production, and the transformation from subsistence to commercial agriculture. Similar to the manner in which 'green revolution' in Kenya has risen, and perhaps fallen (Yuksel, 2013), on the need to enhance Kenya's food self-sufficiency, digital transformation is hoped to be the next revolution in agriculture (Kudama et al., 2022; Steinke et al., 2022). The analysis in this report calls for a much deeper understanding of the political economy of digitalized agriculture in Kenya.

First, the actor networks in the digital ecosystems in the country, and the political economy of these, need further investigation in order to make available knowledge about how digital transformation is affecting capital accumulation in Kenya's agriculture. Whereas digital solutions are largely meant for farmers, there is some evidence that these are not the focus of farmers' demand (Bolwig et al., 2021). Digital solutions are largely projects of commercial private firms, whether foreign or local (Briner et al., 2021). These firms include manufacturers and suppliers of agricultural inputs; ICT companies dealing in software and networks systems; non-agricultural hardware companies manufacturing equipment implements; and companies with interest in food supply chain. Since these companies are profit driven, their commercial interests cannot be dissociated from their investment into the development of the digital solutions. For example, input manufacturers have a greater chance of enhancing sales through efficient digital networks that farmers might be part of. This benefit multiplies further if the network is embedded within larger networks of 'fintech', which offer credit to farmers to access seeds, fertilizers and pesticides. Furthermore, ICT companies like Safaricom, one of the most profitable large companies in Kenya, can leverage digital solutions to reach a wider network and enlarge their customer base, especially for M-Pesa financial services. Looked at through this conceptual lens, digitalisation of agriculture in Kenya is part of the wider project of top-down capitalist market expansion, through assertion of technology essentialism.

Second, digitalisation of agriculture appears to be an extension of 'green revolution', since most digital platforms tend to provide financial services to access farm inputs â€" certified seeds, fertilizers and pesticides. The literature abounds with critique of Africa's 'green revolution' as a tool for expanding corporate capital (Friedmann 2005; Tandon 2011; Berguis and Buseth, 2019). The involvement of governments and development agencies in expanding the agricultural digital solutions reflects the 'green revolution' agenda for smallholders, which attributes poverty among smallholders as being due to their lack of access to farm input like certified seeds, fertilizers and pesticides â€" and therefore their need for support from the State and partners to provide these agricultural inputs to them (Hebinck and Kiaka, 2024). The 'green revolution' has forged a close and problematic connection between governments and public development financing and private multinational input companies like Bayer and Monsanto. Similarities emerge from the development and marketing of pro-smallholder digital technologies which are largely embedded in public-private partnerships, and with financing from development agencies.

Third, the links between digitalisation and development aid deserve interrogation. Some of those designing digital solutions targeting smallholders are able to tap into development cooperation funding from donor countries. These include the US government through USAID, the Dutch government through SNV and the German government through GIZ. These intermediaries of development cooperation provide funding support to private sector institutions or start-up companies that design and promote digital solutions to enable farmers to access inputs and other services from multinational companies. In this sense, digital tech can be said to serve the purpose of expanding markets for agribusiness, financial and other related interests. Especially with rising right-wing politics in Europe and US (Greven, 2016), development cooperation is increasingly taking the shape of aid-for-trade, where donor funding is actively embedded in trade relations between donor-recipient countries. Much as the approach seems to be increasing the capacity of poor farmers to access needed digital solutions, one prediction can be surely lucid from the analysis in this report â€" that digitalization of agriculture is an extension of the problematic use of public funds to support the expansion of capitalism and capital investment of profiteering companies, whether directly or indirectly. Empirical research could go into examining how state-mediated digital solutions in agriculture aid the expansion of corporation hegemony in the new food production fronts in Kenya.

Fourth, as agricultural digitalisation advances in Kenya, more political economy debates will arise owing to its entanglement with capitalist philanthropists. The involvement of capitalist philanthropists like the Gates Foundation, Rockefeller Foundation, Bayer Foundation and Syngenta Foundation for Sustainable Agriculture in developing digital solutions in agriculture are obviously aligned with the commercial interests of companies whose products and services are supported or acknowledged by philanthropists' policies. These include the input manufacturing companies, ICT firms and associated hardware developers, who stand to ostensibly benefit. In the literature, a fundamental problem of capitalist philanthropy is the reaffirmation of modernisation theory through knowledge supremacy (Canfield, 2022). Agricultural digitalisation is supported on the basis that local knowledge is inferior to tackle the challenges facing agriculture today, especially in light of climate change (Kusunose and Mahmood, 2016; Kogo et al., 2021).

Fifth, how digital and indigenous forms of knowledge combine should be investigated. Funding support to foreign-based research institutions like CGIAR and start-up companies from the North are partly based on the need to diffuse tech knowledge to smallholders to replace their unresponsive knowledge and experience. Digital solutions that offer farm advisory services on which seeds to plant in what conditions are much in use. The fact that these services are based on farmer subscription adds another difficulty, which is the the commercialisation of agricultural knowledge. Empirical research could illuminate if digitalization is leading to overreliance on commercialised farming knowledge, in a similar manner to Africa's 'green revolution' created overdependence on the market for seeds, fertilizers and pest control.

There is evidence that some smallholder farmers in Kenya have resisted the 'green revolution' to plant their locally-developed seed or 'landraces' even in areas with heavy presence of projects supported by capitalist philanthropists (Almekinders et al., 2021; Hebinck and Kiaka, 2024). Research should explore how smallholder farmers perceive and practically interact with the new digital knowledge on farming, and what explains level of uptake (Kimanthi and Hebinck, 2018).

Finally, to understand the governance of data in digital solutions, a fundamental question worth exploring is whether the policies and legislation that have only recently emerged can ensure robust data governance. As shown by the increasing cases of cybercrime show, data privacy, ownership and security is a crucial threat to many digital solutions in Kenya's economy. Whereas the government have formulated good laws to deal with the problem of data privacy and security, if not strictly enforced, the good laws are good as non-existing. Taylor (2017) considers the question of 'data justice' in light of current datafication that goes on in various economies. Data justice refers to fairness in the way people are made visible, represented and treated as a result of their production of digital data (Taylor, 2017). Whereas the Data Protection Act (Republic of Kenya, 2019) is robust to recognize the rights of data subjects and responsibilities of data handlers, and to allocate fairly the outcomes of data, it is only the enforcement of the laws and policies that will ensure all dimensions of justice. The Kenya open access data initiatives promises data sharing and conceptualizes agricultural data as common property or a public good (Mungai and van Belle, 2018). The government has established a shared agricultural data platform to this effect. We are unsure for now which of the companies providing digital tech solutions for agriculture have signed up to the data platform. The bold step should be critically examined within the context of the political economy of digital solutions in agriculture - that is, the roles, power and influence that each actor (farmers, the state, local start-ups, multinational corporations, civil society and others) have over the data and the datafication process.

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ANNEX

Table 2: Table summarizing some selected digital tech in Kenya's agriculture

Name of company	Country of origin and partners	Partners and investors	Category of farmers	Service sector	Service supplied	Technology	Number of farmers reached
FutureWater (ThirdEye Project)	The Netherlands Lead company FutureWater is Dutch Funding from USAID, Dutch-SNV		Small scale Medium Large scale	Farm advisory and information	Supports farmers with flying sensors to enable them to improve decision making on seeds, water, fertilizers and labour.	Drones and mobile phone	>2,000 SSFs
Trans-African Hydro-Meteorological Observatory (THAMO)	The Netherlands			Farm advisory and information	Builds digital weather stations in Kenya and is part of Large project in Africa. Weather data is freely available to farmers and can enhance crop modelling and crop insurance.	Weather stations running on GPRS technology.	NA
Astral Aerial Solutions	Kenya		Large scale	Farm advisory and information	Uses drones to help farmers monitor their farm production through: - Mapping of farms - Crop spraying against diseases and pests - Provide crop health maps that give the geo – location of areas exhibiting physical and health variabilities (hotspots).	Drones	Provided drone services to DigiFarm
DroneCrops Ventures	Kenya	Not public	Large scale	Farm advisory and information Farm production management	- Provides precise and targeted application of fertilizers, pesticides, and herbicides to minimize wastage and reduces environmental impact and increases overall crop yields. - Provide mapping and imaging services that enable farmers to obtain accurate and up-to-date data about their fields. I.e. detailed information about crop health, soil conditions, and pest infestations, allowing farmers to make data-driven decisions and implement proactive measures for crop protection	Drones technology IoT sensors and cameras	
Fintech Technologies							
AgriBora	Germany and Kenya		Small scale farmers	Financial management Market information and linkages	Using satellite data AgriBora provides information and advise to farmers to help them increase productivity. It also provides data that helps farmers to get credits providing them with financial inclusion.	Mobile App	1.5 million

Name of company	Country of origin and partners	Partners and investors	Category of farmers	Service sector	Service supplied	Technology	Number of farmers reached
				Farm advisory and information			
eProd	Netherlands	USAID GIZ KFW SNV	Small scale farmers and large scale farmers Works with cooperatives as well	Supply-chain management	eProd offers an affordable Supply Chain Management System for agribusinesses and cooperatives	Big data technologies	
DigiFarm	Kenya	Safaricom Ltd.	Small scale farmers	Financial management Market information and linkages Farm advisory and information	Uses big data t		
Apollo Agriculture	Netherlands		Small scale farmers	Financial management Market information and linkages Farm advisory and information	Delivers a customized package of credits to farmers, high-quality farm inputs, and advice that can double farm yields. Apollo assesses farmer credit risk and customizes each package to a farmer's specific location using satellite data, soil data, farmer behavior data, and crop yield models.	Agronomic machine learning Remote sensing Mobile phone App. technology	
Synnefa Cloud	Kenya	Google startups		Market information and linkages Farm advisory and information	Provides an online farm record-keeping software as a service and integrate this platform with IoT solar-powered soil sensors to give farmers a 360-degree view of their farm and eliminate any guesswork.	Machine learning Internet of Things – soil sensors	
AfriAgrimark	Kenya	Cisco	Small scale farmers	Financial management Market information and linkages Supply chain management	Connects farmers, truckers and vendors in the same direction to enhance markets for fresh vegetables. Distributed ledger and AI to automatically synchronize information between vendors, truckers, and farmers on delivery time, routes, locations, and available truck space in real-time.	Distributed ledger Artificial Intelligence Mobile App	
Lentera Africa	Kenya	MassChallenge, USA		Financial management	Comines satellite-based demand planning with a mobile-based platform for farm	Satellite Computer Visioning	

Name of company	Country of origin and partners	Partners and investors	Category of farmers	Service sector	Service supplied	Technology	Number of farmers reached
		SAIS - Scaling digital agriculture innovations through start-ups in Africa, Germany		Market information and linkages	produce aggregation. Lentera's data is used by farmers, agribusinesses, banks, and insurance companies for better demand planning and sourcing strategies.	Mobile Apps	
FarmIT	Kenya	Not disclosed	Small scale farmers (Horticulture)	Market information and linkages Farm advisory and information	- FarmIT is a mobile based information platform that offers precision agricultural advisories and market linkage services to smallholder vegetable farmers (planting Water melons, tomatoes, Irish potatoes, cabbages, spinach, collards, sweet pepper and carrots). - Matching smallholder farmer groups to affordable input service providers using a mobile platform for enhanced mechanization of agriculture. - Provides farmers with real-time information to help make right decisions at key stages of crop production cycle	Mobile App Satellite Artificial Intelligence	365,000
Grey Edge Monitoring	Kenya			Farm advisory and information	- Crop diseases detection and reporting - Pests and insects monitoring - Soil moisture monitoring and management - Nutrient deficiency monitoring - Daily weather monitoring - Emergency monitoring - Gives summary statistics for every field	Satellite imagery Soil sensors	
Lima Labs	Kenya	Esor Investments, Germany Arché Gruppe, Germany	Small scale farmers	Farm advisory and information	- Ditigizes farms data to help reduce waste and increase productivity with data. The company's platform uses an artificial intelligence engine to learn how crops grow on the farm and monitors crops in real-time with IoT cameras, enabling farmers to grow crops in an advanced way.	- Artificial Intelligence - Internet of Things cameras	
Water Watch Foundation	Netherlands	SAP, Germany Next View Consulting, EU Infoplaza, Netherlands		Farm advisory and information	- Provides early warning alerts on diseases that can affect potatoes, and offer them advice on what to do, thereby	- Satellite imageries - IoT cameras - Weather information	800,000 farmers

Name of company	Country of origin and partners	Partners and investors	Category of farmers	Service sector	Service supplied	Technology	Number of farmers reached
					helping farmers to avert loss and increase yield by 20-40%.		

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