

APPLICATION OF DIGITAL TECHNOLOGIES IN AGRICULTURE: A REVIEW OF THE PRACTICE AND OPPORTUNITIES FOR SMALLHOLDER FARMERS

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ABSTRACT

The recent emergence of digital technologies is rapidly transforming the efficiency, effectiveness, and transparency of agricultural production. Smallholder farmers (SHFs) often have limited access to credit facilities, are poorly trained, use old farming tools and practices, and face difficulties managing post-harvest losses and accessing suitable markets for their produce. Changes in climatic conditions and the unpredictability of weather patterns have expounded the current challenges. Digital technology offers scalable opportunities to bridge the gaps and increase the resilience of SHFs in sustaining food production. This study focused on the application of four independent variables of digital technologies by smallholder farmers; use of digital lending technology to access capital and credit facilities; the availability of digital agricultural extension services; the use of digital technology for market linkages and the use of digitally improved tools and farming techniques. The results showed that smallholder farmers who have been trained in digital technologies and use digitally improved tools & modern farming techniques have derived the most benefit and increased output. Precision agriculture, data-driven decision-making at the farm levels, and integration of other agri-service platforms have helped in improving efficiency, productivity, and sustainability across the whole agricultural value chain. There is still greater opportunity to enhance digital lending platforms and digital marketing for agricultural produce.

Keywords: *digital technologies, agriculture, smallholder farmers*

INTRODUCTION

Many studies have shown that the agricultural sector is at the heart of global development. especially in less developed economies. Nonetheless, many developing countries are characterized by low agricultural productivity, high operational costs, inadequate information, and unstructured markets for farmers (Rapsomanikis, 2015). Digital technology has transformed the agricultural sector around the world, bringing significant changes and advancements which has helped in increasing productivity. McFadden et al. (2023) observed that in the USA, digital technology adoption was marked by an increase

in the use of tools such as variable rate technologies (VRT), soil maps, and yield maps in soybean and corn farms across the country. In the last decade, the use of data analytics and information systems has grown exponentially in Africa. As a result, numerous digital innovations have been developed to address the challenges faced by smallholder farmers within the continent. Agri-service digital platforms are positioned to collect data, profile, and help in programming farmer-specific solutions toward reducing the myriad of challenges they face (CGIAR, 2020). However, many of the interventions are still at an early stage and some have been crippled by low uptake due to the assumed risks by the smallholder farmers. Many innovators are thus experimenting with different approaches.

In Northern Ghana, for instance, Abdulai et al. (2023) investigated the use of digital technology among smallholder farmers in the region. They found that the uptake of digital technology was limited mainly due to low digital literacy levels and limited access to digital equipment. Digital extension services are limited to the use of SMS services, interactive voice response (IVR), and radio. These digital solutions are mainly promoted by private sector projects and NGOs operating in the area. The conclusion was that digital use in rural farmers is yet to reach its full potential even though opportunities exist which can help farmers utilize digital platforms and maximize their productivity at the farm level.

Artificial Intelligence (AI) is also being used in several African countries to improve farming activities. According to Degila et al. (2023), AI has been a significant development in countries such as Benin, Burkina Faso, and Cote d'Ivoire. AI technology is utilized in analyzing and managing weather and chemical data and big data. This goes a long way in ensuring that farmers use the right amounts of farm inputs at all levels of the production process which helps in improving efficiency in the farm.

Kenya has launched a project intended to register 1.4 million farming households online and about 2300 agro-dealers in the project known as digitalization for agriculture (D4Ag) by 2023 (Business Daily, 2020). This is a method of locking out brokers in agriculture and shifting farming activities online; it will curb the loss of subsidized inputs and enhance productivity. The Kenya Agricultural and Livestock Research Organization (KALRO) advises farmers on digital farming since it has e-agricultural platforms such as the Kenya Agricultural Observation Platform (KAOP), a website with 30 mobile applications that

cover value chains. The contribution of this research covers application of digital technologies as below:

Access to capital and credit facilities

Despite advancements in technology and the banking sector, access to credit is still a weighty issue facing smallholder farmers in Kenya. Janzen, Magnan, and Mullally (2020) observed that accessing agricultural credit allows farmers to fund their agricultural operations while offering insurance against unexpected shocks. Without financing, smallholder farmers barely afford the relatively high upfront costs of quality seed and fertilizer (Mwangi et al., 2021) resulting instead in low-quality seed and little to no fertilizer. However, most digital loaning platforms provide short repayment periods, starting from one week to one month (Parlasca et al. 2022). The short repayment period does not allow farmers the time to wait for harvesting time to repay their loans (Janzen, Magnan & Mullally, 2020).

Availability of agricultural extension services

Agricultural extension services are critical to the success of smallholder farmers in Kenya. These services provide farmers with information on new farming practices, technologies, and market opportunities, which can help them increase productivity and income. However, access to agricultural extension services in Kenya remains a persistent challenge, particularly for smallholder farmers who comprise most of the farming population. One of the main challenges to accessing agricultural extension services in Kenya is limited funding. The government primarily funds agricultural extension services in Kenya, and budgetary constraints have limited the availability and quality of these services. According to Birch (2010), more extension officers are needed to serve farmers in the country, with the current 1:1000 officer-to-farmer ratio falling way short of the recommended 1:400 extension officer-to-farmer ratio. Another challenge is inadequate infrastructure characterized by poor road and communication networks in rural areas that hinder the delivery of extension services, making it difficult for extension officers to reach remote areas (Ngele, 2015). Finally, some farmers may not be interested in extension services or may not see the services' value. According to Muatha (2014), this can be due to the lack of awareness about the state or availability of extension services, especially among smallholder farmers, as many such farmers fail or are unable to look for effective extension services, which might help them to scale up their agricultural production.

Access to market linkages

Access to markets is critical for smallholder farmers in developing countries as it provides them with a reliable source of income and encourages them to increase their production (Akrong et al., 2021). However, accessing markets is often cited as a challenge that smallholder farmers face, particularly in remote areas. One of the main needs for smallholder farmers in accessing markets for their outputs is market information (Amare et al., 2019). Many smallholder farmers in Kenya are unaware of market prices, demand, and trends, making it challenging to decide what to produce and when to sell. Infrastructure challenges characterized by poor road networks and inadequate storage facilities impede smallholder farmers making it difficult for the farmers to transport their crops to markets and access inputs, such as fertilizers and seeds (Langyintuo, 2020). Inadequate storage facilities for many smallholder farmers result in post-harvest losses, reducing the farmers' profits and making it difficult for them to reinvest in their farms. Digital agricultural market (DAM) initiatives are projected to grow rapidly in the coming years with several organizations working to improve smallholder farmers' access to ready markets at reasonable prices which in turn supports the farmers and improves productivity (Abdelrahman, 2022).

Adoption of digitally improved tools and farming techniques

According to Kiplimo et al. (2015), one of the main challenges smallholder farmers face is financial assistance to purchase modern farming tools and equipment or implement modern farming practices. Many farmers may need access to reliable sources of high-quality inputs, which can affect their productivity and yield (Musyoka, 2017). Additionally, Musyoka (2017) argues that the socio-economic status of many smallholder farmers, which places them in the poverty bracket, hinders such farmers from affording quality farming inputs. Therefore, many remote farmers have to contend with poor-quality inputs, which negatively affects their farm produce. Misaki et al., 2018, indicated that smallholder farmers in Sub-Saharan Africa need more information and knowledge about modern farming practices. Many farmers rely on traditional farming methods passed down from generation to generation. While these methods may have been effective in the past, they need to be revised in today's rapidly changing agricultural landscape. This research work seeks to establish the application of digital technologies in agriculture by reviewing the practice and opportunities for smallholder farmers.

LITERATURE REVIEW

Theoretical Literature Review

Diffusion of Innovation Theory (DIT)

The Diffusion of Innovation theory (DIT) is considered to be one of the oldest social science theories that explain the process through which a technology spreads among a population. It seeks to explain how and why innovations are taken up by individuals. Rogers (2003) identified five attributes of innovations in his seminal book “Diffusion of Innovations”. According to Rogers, the five attributes are relative advantage, compatibility, complexity, trialability, and observability. The DIT theory further suggests that new ideas are spread across society through several actors, namely the innovators, early adopters, early majority, late majority, and laggards (Rogers et al., 2014).

The innovators are always quick to adopt new ideas, technologies, and knowledge, have risk-taking behavior, and therefore can cope with failure and uncertainty (Rogers et al., 2014). The innovators play a significant role in introducing new technologies into society and will play a part in the flow of information to others in the system. Early adopters usually are respected members of a social system. According to the DIT theory, early adopters are opinion leaders and have a closer connection with the social system than innovators. Early adopters are aware of the need for change and are therefore likely to take up new ideas and innovations. They can also spark a critical mass once they start using the latest technology, as people can see this as a stamp of approval to use the invention. The early majority, according to the DIT theory, always look for evidence of the success of the innovation before they can start using the specific invention (Rogers et al., 2014).

They will adopt innovations before the average individual and rarely perform leadership duties in society. The late majority are cautious of taking up innovations and can perceive new technologies with skepticism (Rogers et al., 2014). They will always question innovations, and their adoption decision is mainly due to peer pressure or a necessity rather than their own free will to change or use new technologies. They are likely to have limited resources, and therefore risks associated with the technology must be addressed before they can adopt the new technology (Rogers et al., 2014). Laggards are the last to adopt new technologies. They are risk-averse, and due to their vulnerable economic conditions, they have limited access to resources to adopt new technologies. The DIT theory was applied in the study to establish the diffusion categories and explain why some sections of the target

population have adopted digital technologies and others are yet to and what measures need to be put in place to reduce the resistance to change and increase adoption.

Theory of Financial Innovations

According to Mention and Torkkeli (2012), innovation in financial services has long been considered conservative. They observed the natural tendency of financial firms to adopt a risk-averse attitude, combined with the common belief that most financial innovations are mere imitations of existing products. Over the years, innovations in financial institutions have had a strong emphasis on technology-induced and enabled platforms, such as ATMs, mobile banking, e-banking, video banking, and the like (Consoli, 2008; Pennings and Hariento, 1992). The role of ICT cannot be ignored in shaping innovations in financial services. Mention and Torkkeli (2012) define beneficial financial innovation as the type of innovation that serves the interests of individual customers, households, and states, thus positively affecting the functioning of society as a whole. Innovation in financial services is intangible and multifaceted, with the traditional distinction between product, service, and process innovations being largely irrelevant, as it also applies to most service industries (de Jong et al., 2003).

The outcome of the financial innovation process is usually through a combination of changes in the offerings of banks, insurance companies, investment funds, and other financial service firms and frequently results in a bundle of new products and services coupled with new ways of interacting with customers and distribution channels. Nevertheless, financial innovations remain easily imitable and their diffusion across competing institutions is fast (Roberts and Amit, 2003). Product innovation has also been evidenced to experience a relatively short lifecycle, as a result of disclosure requirements and lack of formal protection mechanisms (Rossignoli and Arnaboldi, 2009).

In the current study, the theory of financial innovation was applied to investigate the issues with the traditional form of money lending that necessitated the innovation of digital lending services to enable easy access to credit among smallholder farmers. It is hypothesized that with advancements in digital platforms, smallholder farmers will be able to access loans, training, extension services, insurance services and market linkages that will improve their productivity.

Self-Determination Theory

The Self-Determination Theory (SDT) is one of the many theories that begun from motivation research forwarded by Deci and Ryan (1985). The Self-Determination Theory suggests that self-determination is a human trait that involves choice experience and making choices from a pool of choices (Deci & Ryan, 1985). Deci et al. (1991) suggested that choice could be a regulatory process if the behavior is self-determined. The motivation model supports psychological research in explaining the behavior observed in people. The key parts of the SDT and the motivational model is extrinsic motivation and intrinsic motivation. Extrinsic involves the outcomes unique from the activity itself, while intrinsic motivation involves the consequences of acting. According to Davis et al. (1992), perceived usefulness can be considered to be an intrinsic motivational trait, while enjoyment can be extrinsic.

Risk perception by customers usually arises due to the doubt related to the degree of inconsistency between customers' judgment and real behaviour, and technology failure to deliver its anticipated outcome and its consequent loss (Chen 2008; Koenig-Lewis 2010; Lee et al. 2007). In the context of digital technology, the perception of risk is even more important due to the threat of privacy and security concerns (Luarn & Lin 2005). Secondly, fear of loss of PIN codes may also pose security threats (Kuisma et al. 2007). Thirdly, some users also fear that hackers may access their bank accounts via stolen PIN codes (Poon 2008). Finally, some users may also have a fear of loss or theft of a mobile device with stored data (Coursaris et al. 2003). The self-determination theory is relevant in the current study because it is hypothesized that the perceived benefits of using digital platforms can motivate smallholders to adopt the technology, resulting in increased productivity.

Empirical Literature Review

Digital technology and access to capital among smallholder farmers

Smallholder farmers have limited access to capital and financial services, especially in developing countries such as Kenya (Kirui et al., 2010). Numerous conventional credit providers such as microfinance institutions and commercial banks are wary of supplying credit to smallholder farmers, due to risks that come with traditional farming activities (Ruiz, 2014; Lambon-Quayefio et al., 2019). In their study, Sarfo et al. (2021) observed that access to capital is a limitation for many farmers mainly due to the high transaction costs that credit companies charge, especially in rural areas. Balana and

Oyeyemi (2022) highlighted various interlinking factors hindering access to credit including the risk-averse nature of smallholder farmers, high transaction costs, and a need for more awareness or information asymmetry regarding financial credit services. The authors call these factors the demand side factors, which are predominantly associated with farmers in rural areas in developing countries. Due to the limitations that come with traditional financial and lending services, many farmers are increasingly switching to digital financial services (DFS) for their credit options. Mobile phones are reducing the costs associated with money lending and connecting numerous farmers to digital lending platforms (Pazarbasioglu et al., 2020). Through the data collected through digital platforms many smallholder farmers are finding it more accessible to obtain lending via digital lending platforms (Lambon-Quayefio et al., 2019). However, digital lending platforms also have associated risks. For instance, due to poverty levels, farmers can fall into debts that they might be unable to repay (Lambon-Quayefio et al., 2019).

This makes the adoption of such digital loans unfavorable to smallholder farmers. Furthermore, digital loans have a short repayment period which does not allow farmers to harvest their produce to repay these loans. Also, digital loans do not take into account risks such as crop failure which could lead to significant financial losses on the farmer's part. It is therefore important to determine the factors that lead to limited access to credit and to develop practical solutions to ensure that smallholder farmers can access credit services, which can go a long way in helping them improve their farming operations.

Digital technology and agricultural extension services among smallholder farmers

Traditional forms of extension services in developing countries usually involve public extension services, where extension officers frequently visit rural farms to educate and provide vital information to farmer groups or individual farmers (Rajkhowa and Qaim, 2021). Many farmers in rural areas in developing countries relied solely on the information from the extension officers. If the extension officers failed to show up, vital information could not be provided, which would affect their productivity. In a study by Ndimbo et al. (2023) in Tanzania, the researchers wanted to determine the impact of digital technology on agricultural productivity in rural areas.

The results highlighted a correlation between using ICT tools such as mobile phones and increased agricultural productivity, which inevitably leads to improved livelihoods in rural

areas. The authors observed that in Tanzania, there needs to be more public extension officers who help farmers get vital information and skills to improve their agricultural production activities. Since farmers have no adequate access to public extension services, they are forced to adapt their methods and, in this way, adopt digital tools such as mobile phones. These ICT tools become vital in accessing agricultural information, which helps them to improve their agricultural production. According to Ndimbo et al. (2023), digital technology has been an important development in the Tanzanian rural agricultural sector because it fills the gap left by the inadequate supply of extension agents and allows smallholder farmers in rural areas get access to crucial agricultural-related information which helps them to increase their production and farm income.

These findings are similar to the results obtained by Rajkhowa and Qaim (2021), who conducted a study in rural India and wanted to investigate the impact of personalized digital extension services on agricultural performance among smallholder farmers in the country. They observed that an inadequate supply of public extension agents left a significant gap in the flow of agricultural information to rural farmers. Before the introduction of digital extension services, farmers faced severe challenges in accessing vital agricultural-related information, affecting their productivity. However, with advancements in digital tools in the agricultural field, smallholder farmers in India could even be provided with personalized information such as what type of plant to grow, when to plant, other methods of production they could use and the inputs to use, including their types and quantities. The results indicated that advancement in digital systems helped smallholder farmers in rural areas access extension services, which was otherwise difficult with traditional extension services from the public sector. Rajkhowa and Qaim (2021) also concluded that, through personalized extension services, farmers could maximize their input use, diversify their production, and increase their yield, which led to increased farm income.

Another way in which digital technology can be used to enhance agricultural extension services is through the use of drones. Drones can monitor crops and assess soil fertility (Javaid et al., 2022). This can help farmers identify problems early on and take corrective action before they become more serious. In addition to these technological solutions, digital technology can create online communities where farmers can share information and best practices. For example, the Farmerline platform in Ghana connects farmers with agricultural experts, allowing them to share information and learn from each other's

experiences (Farmerline, 2023). Such advancements in technology in the agricultural sector allow smallholder farmers to obtain valuable information to maximize their operations, ensuring they can increase their farming income.

Digital technology and access to market linkages among smallholder farmers

In a study by Ismail (2023) in Tanzania, where the author sought to establish whether digital technology could bridge this gap and ensure that smallholder farmers in rural areas could access markets where they could get favorable prices for their produce, the author observed that many smallholder farmers in developing countries opt to sell at the farm gate due to challenges associated with market participation. It is a fact that farm gate prices are very low compared to market prices, and therefore farmers in rural areas do not get to benefit as they deserve. The results from the study showed that digital technology can play an important role in linking farmers to markets. Applications such as Twitter and WhatsApp were particularly important in helping farmers exchange information about various subjects, such as available markets.

Access to market linkages is a critical challenge facing smallholder farmers in developing countries such as Kenya. Digital technology can help smallholder farmers access input markets through e-commerce platforms (Birner et al., 2021). These platforms allow farmers to purchase agricultural inputs such as seeds, fertilizers, and pesticides online, eliminating the need to physically travel to input markets. This can save farmers time and money while allowing them to access a broader range of inputs. Furthermore, digital technology can help farmers access information about input prices and availability, enabling them to make more informed decisions about when and where to purchase inputs (Onsomu et al., 2022). The M-Farm app in Kenya provides farmers with real-time information about input prices, helping them negotiate better prices with input suppliers.

Digital technology can therefore help smallholder farmers access output markets by connecting them with buyers and markets beyond their local area. For example, platforms such as Twiga Foods in Kenya connect smallholder farmers with large-scale retailers, allowing them to sell their produce at better prices than they would get at local markets (Global Agriculture and Food Security Program, 2018). By connecting farmers with more extensive and diverse markets, digital technology can help them earn higher incomes and improve their livelihoods.

Use of digitally improved tools and farming practices among smallholder farmers

Digital technology and modern farming practices have the potential to address some of the challenges faced by smallholder farmers by improving productivity, reducing costs, and increasing efficiency. Digital technology like drones can significantly improve precision farming (Javaid et al., 2022) and help smallholder farmers in developing countries access critical information on weather patterns, market prices, and new farming techniques, which will go a long way in enabling the farmers to practice modern farming in all aspects of their operations on the farm. To enhance modern and smart farming, digital tools offer a range of technologies (e.g., sensors) on different machines or devices that are used to collect data on moisture, soil fertility, weather conditions, and plant health, and stream this data wirelessly to cloud servers for analysis and prediction of harvest dates, yield quantities and quality.

The cloud may provide feedback and decision support to the farmer on his/her smart phone and send pertinent information to other clouds or parts of the value chain, where data from many different farmers may be collated and processed into information useful for transportation and marketing logistics, and the management of financial markets (Buckmaster, 2016; Clifford, 2016). However, smallholder farmers' adoption of digital technology in developing countries has been slow with some citing lacking access to reliable electricity or internet services, installation costs and many farmers lack the necessary technical skills to use digitally improved tools effectively.

Summary of Research gaps

This section provides a summary of past studies on the topic. The studies touch on different aspects and variables which have not been extensively covered in the past and require additional research to offer new knowledge on the subject. This study, therefore, seeks to establish the effect of digital technology on agricultural production among smallholder farmers focusing on Machakos County.

Table 5

Summary of the Literature Review and the Research Gaps

Author and Year	Title	Methodology and Findings	Research Gap	Focus on the Current Study
Pazarbasioglu et al., (2020)	“Digital Financial Services” – April 2020 World Bank	The study used case studies on different countries to analyze the adoption of digital financial services. The findings of the Kenyan case study showed that the country had one of the most extensive m-services coverage among many nations on the African continent. The conclusions of the report showed that even though digital financial services were widely used, there remain significant risks on the part of the customer. Many private digital finance providers have entered the market, and users risk exploitation.	The study broadly assessed the level of awareness and adoption of digital financial services and did not focus on smallholder farmers.	To bridge the research gap, the focus of this study includes other aspects of digital technologies besides financial services and it is specific to smallholder farmers in Kenya’s Machakos County.
Javaid et al. (2022)	Enhancing smart farming through the applications of Agriculture 4.0 technologies	The study used an exploratory approach to describe the benefits and potential of digital agriculture in enabling smart and precision farming among smallholder farmers. The discussion from the study showed that modern technology has significant potential in improving the farming practices of farmers.	The study focused on the developed countries. The same research could be done in developing nations where there are many smallholder farmers who lack access to such farming technologies.	The current study made reference to the findings of this research on the background of the study and further contextualize the findings to the smallholder farmers in Machakos County.

Table 1*Summary of the Literature Review and the Research Gaps*

Mugo (2019)	Digital Input Loans for Smallholders – how can providers optimize uptake and repayment?	The study used case studies in various counties in Kenya, namely Meru, Tharaka Nithi and Bomet. It used no-representative and snowballing sampling techniques to survey smallholder farmers from these counties. The findings indicated that short-term loans were not applied by smallholder farmers who felt that the short repayment period did not allow them to harvest their crops so that they could repay the loan. Also, the results from the survey showed that farmers perceived a lack of sufficient time allowed to apply for digital loans.	The study focused on two primary digital loan platforms (DigiFarm and FEMA) and did not consider other m-service providers. The study focused on the factors that could help improve the uptake of digital financial services among smallholder farmers.	The current study identified four key independent variables with digital lending as one of the variables. This study thus enhanced the previous findings and investigated the broader correlation of digital technology to agricultural production among SHFs. Further, the scope of the current study is Machakos County.
Baumüller (2015)	Assessing the role of mobile phones in offering price information and market linkages: The case of M-Farm in Kenya	The findings from the survey indicated that farmers had positive perceptions regarding digital technologies in their farming activities. The M-Farm platform, which was the primary technology used in the study, also showed that digital financial technologies helped farmers plan their production processes which in turn helped in increasing their yield and incomes.	The study only relied on farmers' perceptions regarding m-services and therefore could not be relied on to offer conclusive results. Furthermore, the study was limited to only two study sites where farmers could access the M-Farm platform.	The current will investigate digital linkages to market as one of the variables among three others. This study will therefore enhance the previous findings and investigate the correlation of digital technology to agricultural production among SHFs.

Conceptual framework

The conceptualization and operationalization of the variables for this study is shown in Figure 1 and Table 2 respectively.

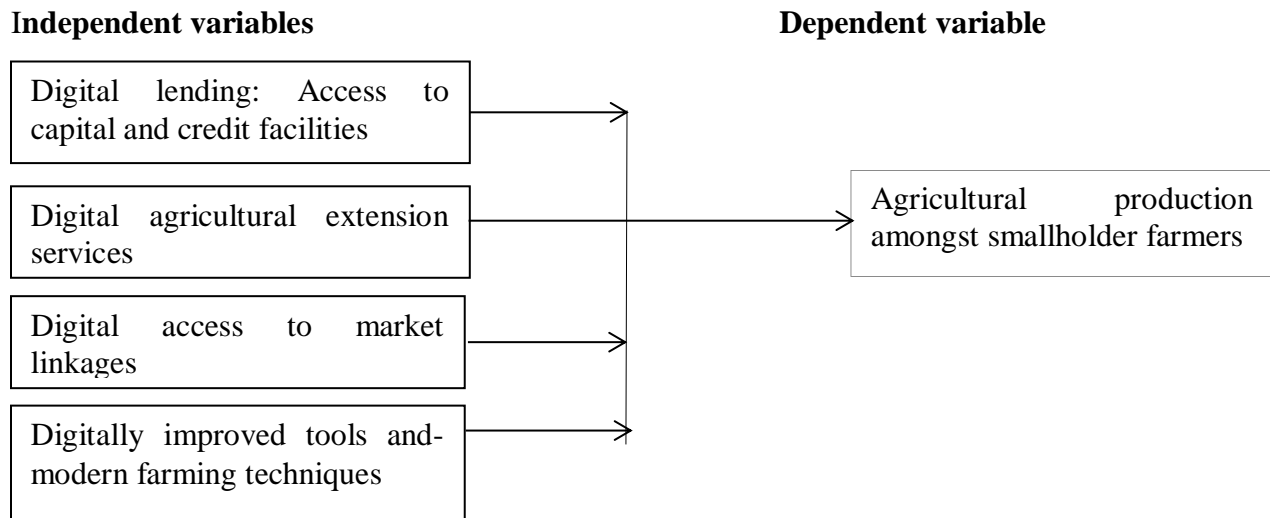


Figure 1: Conceptual Framework

Table 6: Operationalization of Variables

Research Objectives	Type of variables	Indicators	Measurement scale	Tools of analysis
Digital lending for capital and credit facilities	- Accessibility - Frequency	- Sources - Cost of lending - Perceived risks	Nominal and ordinal scale	Quantitative: percentages, frequencies, SPSS analysis
Digital agricultural extension services	- Availability - Convenience - Reliability	- Duration of use - Frequency - Level of training	Nominal and ordinal scale	Quantitative: percentages, frequencies, SPSS analysis
Digital agricultural market linkages	- Ease of access - Reach	- Price - farm gate versus market. - Post-harvest losses - Income/Savings	Nominal and ordinal scale	Quantitative: percentages, frequencies, SPSS analysis
Digitally improved tools and farming practices	- Farming tools and techniques - Farming method - Suitability	- Use - Initial investment - Effectiveness	Nominal and ordinal scale	Quantitative: percentages, frequencies, SPSS analysis

RESEARCH METHODOLOGY

This study focused on determining the effect of digital technology on agricultural production among smallholder farmers Machakos County in Kenya. A combination of two types of quantitative designs namely the survey research and correlational research designs were applied.

Target Population

The target population will be smallholder farmers in Machakos County in Kenya as shown in Table 3.

Table 7: Target Population Distribution

Sub-County	Total population of SHFs	Sample size
Machakos – Central & Kalama	13,250	21
Mwala	39,345	62
Matungulu	31,701	50
Kathiani	22,014	35
Kangundo	36,893	59
Yatta	33,960	54
Masinga	25,465	40
Mavoko	40,100	64

Source: 2019 Machakos County Agricultural Extension Office

Some of the crops grown by smallholder farmers in Machakos County include pigeon peas, beans, sweet potatoes, and maize in some parts of the county. Smallholder farmers in the county also grow fruits such as mango and pawpaw. Access to land is a significant problem in the county, limiting the amount of land under which farmers can practice farming. Therefore, a majority find themselves with relatively smaller land sizes, forcing them to practice small-scale farming. Furthermore, access to credit limitations and poverty levels means many farmers cannot expand their agricultural businesses.

The smallholder farmers from Machakos are chosen because, despite the challenges, they have shown they can be productive. Also, digital financial platforms are already operating in the county, which can be a significant source of data and information. The sample size of 385 participants was considered sufficient to capture the target population's characteristics. The results from the sample were used to generalize the entire population of the targeted smallholder farmers in Machakos

County. A proportionate sampling technique was used to distribute the calculated sample size of smallholder farmers to each of the eight sub-counties in Machakos County.

The researcher collected data from the target sample of farmers using an interview guide with open-ended and closed questions. The researcher used an open data kit (ODK) for data collection since that kit was economical, easier to administer as well as time-saving (Saunders, Lewis, & Thornhill, 2018). For this study, the researcher carried out a pilot study on 35 participants using telephone calls and face-to-face interviews to area extension officers, field officers from agricultural offices, lead farmers, and managers of digital platforms.

Data collection involved administering the interview questions to the smallholder farmers. The enumerators for the study visited the farmers in their homes and guided the participants and filled in the ODK questionnaire. The collected responses were scrutinized, coded, and analyzed using various statistical software. Inferential data analysis methodologies were employed to allow for conclusions to be made about the population. Correlation and regression analysis were applied to determine and explain the effect of each of the independent variables in digital technologies on agricultural production. To test variables were:

Y = Dependent variable (Agricultural production)

β_i = Coefficients (predicted)

X_i = Independent variables

X₁ = Use of digital lending for capital and credit facilities

X₂ = Availability of digital extension services

X₃ = Use of digital technology for market linkages

X₄ = Adoption of digitally improved tools and farming practices

□ = error term

Graphs and charts were used to present the data collected. Ethical considerations were also made regarding informed consent, voluntary participation, confidentiality, privacy, and anonymity.

RESEARCH FINDINGS

Three hundred and fifty farmers in Machakos County were interviewed for this work. Respondents were drawn from all the 8 sub-counties in the County as shown on the Table 4.

Table 8: Response Rate by Sub counties

Location	Respondents	Percentage
Machakos–Central & Kalama	20	7
Mwala	38	11
Matungulu	50	14
Kathiani	35	10
Kangundo	59	17
Yatta	54	15
Masinga	40	11
Mavoko	54	15
Total	350	100

From the descriptive analysis, the overarching observation was that smallholder farmers who received training on the use of agricultural digital platforms reported a higher production increase by about 11% as compared to those who had not received any training on the use of agricultural digital platforms. However, this difference is not significant since regression result showed the p-value of 0.086 i.e. greater than 0.05. About 0.0057% variation in the production increase has been explained by training on the use of agricultural digital platforms in the model. This variation is a small indication that there are other factors that contributed to the increase in agricultural production that were not included in the model. This model, $Y = 45.52989 + 11.10479$ (Digital Platform, Yes), was rejected as it was not significant.

- **Digital lending for access to capital and credit facilities**

The study revealed that the largest source of funds for smallholder farmers is personal finances which included salaries, savings, or inheritance money. Overall 89% of the respondents reported using their personal finances together with finances from other sources. Loans from financial institutions, SACCOs, and Chamas were the second most popular source of financing (37%), with digital platforms being the least at 22%. 7% of the respondents reported they obtained financing all the sources.

The respondents who had used digital lending platforms (n=247) further reported that their preference for digital lending was because it offers faster disbursements, flexible repayment plans and no collateral was required. This was seen to have a positive result in enabling the SHFs meet their pressing and immediate financial needs, specifically the purchase farm inputs, fertilizers and

during post-harvest management. However, there were concerns on credit period and risk of blacklisting with CRB stood out as deterrents to digital lending.

After conducting the regression analysis using the dummy variables of having used digital technologies to finance farming operations (Yes or No), there was no significant difference in production increase between those who have used digital technologies to finance their farming operations and those who have not. The overall model was not significant (p-value =0.6830) at 95% confidence. The variation in the production explained by the use of digital technology in financing is about 0.0005% (R-square).

Regression Equation 1: $Y = 53.08232 - 3.0533X_1 + 7.47168$, where

Y is the production increase, X_1 is the digital lending technology

- **Availability of digital agricultural extension services**

The three commonly used technologies for digital extension service are radio/television, videos and mobile phones. Digital extension tools (DETs) generally give information that is perceived as critical, but in short frequent messages. The messages are tailor-made for the smallholder farmers and may include market prices, weather reports or specific, short advisories on a pest outbreak. A total of two hundred and forty-nine (71%) of the respondents indicated that they use digital extension tools. The findings also revealed that SHFs use DETs because the services are easily accessible for farmers, are affordable, give real-time information, are well tailored for the unique needs of farmers, and equip farmers with new skills and knowledge.

With 'No' as the reference base value, there was a higher production increase by about 18.33 for farmers who have used digital extension services as compared to those who have never used digital extension services. In other words, the base production increase is 39.49 for farmers who have never used digital extension services, but higher by 18.33 for those who have used digital extension services.

Regression Equation 2: $Y = 39.48893 + 18.33048X_2$ (yes, no), where

Y is the production increase, X_2 is the digital extension services

- **Use of digital technology for market linkages**

Access to markets and value-adding services are critical for ensuring that smallholder farmers can earn a livelihood as well as keep their farming operations afloat. Of the respondents who have used digital platforms, a majority agreed that access to the market is crucial. Additionally, seventy-three percent of all the respondents agreed that using digital platforms for market linkages and value-adding services was very likely to have a positive impact on agricultural production. However, none of the differences are significant since all the p-values ($p > |t|$) are less than 0.05. The R-square (0.0204) value is very small showing that the model explains little variation in the production increase. The overall p-value (0.1318) is not significant at 95% confidence

Regression Equation 3: $Y = 60.0461 - 18.8286X_3$, where

Y is the production increase, X_3 is the summation of probabilities for the use of digital technology for marketing

- **Use of digitally improved tools and farming techniques**

In this study, the farmers interviewed were largely subsistence farmers (75%), practicing mixed farming (40%). The study further revealed that of the farmers who practiced monoculture, it was dominated by the farming of cereals and pulses. Additionally, of those that grew crops more than two-thirds reported that they practiced crop rotation, used hybrid seeds, and chemical fertilizers. The analysis examined how the use of different kinds of tools and equipment affects agricultural production with three levels of options provided (traditional, hybrid and modern). The analysis revealed that farmers who used hybrid methods have a higher production by about 33.4652 than those using traditional tools and equipment (base reference). Similarly, farmers that use modern tools and equipment have a higher production increase of 12,30012 compared to the traditional tools. The regression model is not significant since the p-value is less than 0.05 and almost 0% variation in the agricultural production has been explained by the kind of tools and equipment used.

$Y = 39.86813 + 33.4652$ (Hybrid), yes or no $+12.30012$ (Modern), yes or no

Y is the production increase

CONCLUSION AND RECOMMENDATIONS

In their study, Pauschinger and Klauser (2022) concluded that digital technologies have helped to transform the agricultural sector into becoming effective and highly productive. This research work arrived at the same conclusion as highlighted below:

Digital lending

Digital lending technology offers smallholder farmers additional sources to access to capital and credit facilities, amid concerns about data privacy, rigorous credit screening, blacklisting in case of default, and high transactional costs as the key limiting factors to higher uptake. With the expansion of internet services in the country, capital lenders, venture capitalists, and other investors need to leverage this opportunity and tailor-make lending solutions that meet the specific needs of smallholder farmers. This conclusion is aligned with the conclusions of Mugo (2019).

Digital extension services

There is a need to promote digital literacy and training among smallholder farmers as well as capacity-building programs and the use of technology. There should be the incorporation of farmer education programs, agricultural training institutions, and extension services to enhance the digital literacy and knowledge of farmers and skills in utilizing digital technology for better agricultural practices.

Digital market linkages

To reach wider markets, the providers of digital linkages to markets have an opportunity to assist SHF aggregate their produce and offer route-to-market solutions, value chains and market systems. The value chains include storage to manage post-harvest losses, transportation, processing and other value addition services. Opportunities in post-harvest management include produce aggregation for homogeneous farmers within the County and thereafter access to upstream value-chains.

Digitally improved tools and farming techniques

According to Singh (2020), modern agricultural production relies on monitoring crop status by observing and measuring variables such as soil condition, plant health, fertilizer and pesticide effect, irrigation, and crop yield. From the analysis, the relationship between the use of digitally

improved tools and farming techniques and agricultural production was inferred with variations indicating that there are other factors that influence agricultural production that were not been included in the model. Precision agriculture uses a large amount of data and information to improve the use of agricultural resources, yields, and the quality of crops (Mulla, 2013).

REFERENCES

- Abdelrahman Ali, Chunping Xia, (2022). *Application of Machine Learning in Agriculture*
<https://www.sciencedirect.com/science/article/pii/B9780323905503000126/>
- Abdulai, A. R., Tetteh Quarshie, P., Duncan, E., & Fraser, E. (2023). Is agricultural digitization a reality among smallholder farmers in Africa? Unpacking farmers' lived realities of engagement with digital tools and services in rural Northern Ghana. *Agriculture & Food Security*, 12(1), 1-14.
- Akrong, R., Mbogoh, S. G., & Irungu, P. (2021). *What factors influence access to and the level of participation in high value mango markets by smallholder farmers in Ghana?*. *Heliyon*, 7(3), e06543.
- Akuku, B., Derksen, H., & Haaksma, G. (2019). *Digital Farming in Kenya*.
- Amare, M., Mariara, J., Oostendorp, R., & Pradhan, M. (2019). *The impact of smallholder farmers' participation in avocado export markets on the labor market, farm yields, sales prices, and incomes in Kenya*. *Land Use Policy*, 88, 104168.
- Balana, B. B., & Oyeyemi, M. A. (2022). Agricultural credit constraints in smallholder farming in developing countries: Evidence from Nigeria. *World Development Sustainability*, 1, 100012.
- Baumüller, H. (2015). Assessing the role of mobile phones in offering price information and market linkages: The case of M-Farm in Kenya. *The Electronic Journal of Information Systems in Developing Countries*, 68(1), 1-16.
- Birch, I. (2018). Agricultural productivity in Kenya: barriers and opportunities.
- Birner, R., Daum, T., & Pray, C. (2021). Who drives the digital revolution in agriculture? A review of supply-side trends, players and challenges. *Applied economic perspectives and policy*, 43(4), 1260-1285.
- Buckmaster, D. (2016). Digital Ag systems in the US & possible lessons for Australia, paper presented at *Digital Disruption in Agriculture Conference, Sydney, 2-3 June, 2016*

- Business Daily. (2020, September 18). *Inside Kenya's new digital strategy to lift agriculture*. Business Daily. <https://www.businessdailyafrica.com/bd/corporate/technology/inside-kenya-s-new-digital-strategy-to-lift-agriculture-2301452>
- CGIAR platform for Big Data in agriculture. CGIAR. (2020, April 24). <https://www.cgiar.org/research/program-platform/platform-for-big-data-in-agriculture/>
- Chen, L., “A model of consumer acceptance of mobile payment,” *International Journal of Mobile Communications*, Vol. 6, No. 1: 32-52, 2008.
- Communications Authority of Kenya. (2020). *Sector statistics report Q4 2019-2020 - Communications Authority of Kenya*. <https://www.ca.go.ke/document/sector-statistics-report-q4-2019-2020/>
- Consoli, Davide, “Systems of Innovation and Industry Evolution: The Case of Retail Banking in the UK”, *Industry and Innovation*, 15.6 (2008):579-600.
- Coursaris, C., K. Hassanein, and M. Head, “M-Commerce in Canada: An Interaction Framework for Wireless Privacy,” *Canadian Journal of Administrative Sciences*, Vol. 20, No. 1: 54-73, 2003.
- Creswell, J. W., & Creswell, J. D. (2018). *Research design: qualitative, quantitative, and mixed methods approaches* (5th ed.). Los Angeles: Sage.
- David J. Mulla, *Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps*, *Biosystems Engineering*, Volume 114, Issue 4,2013,
- Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1992). Extrinsic and intrinsic motivation to use computers in the workplace 1. *Journal of applied social psychology*, 22(14), 1111-1132.
- De Jong, J. P. J., Bruins,A., Dolfsma, W. , Meijaard, J. (2003). *Innovation in service firms explored: What, how and why?* Literature review, Strategic Study B200205, Zoetermeer: EIM Business and Policy Research.
- Deci, E. L., & Ryan, R. (1985). *Motivation and self-determination in human behavior*. Plenum Publishing Co, New York.
- Deci, E. L., Vallerand, R. J., Pelletier, L. G., & Ryan, R. M. (1991). Motivation and education: The self-determination perspective. *Educational psychologist*, 26(3-4), 325-346.
- Degila, J., Tognisse, I. S., Honfoga, A. C., Houetohossou, S. C. A., Sodedji, F. A. K., Avakoudjo, H. G. G., ... & Assogbadjo, A. E. (2023). A Survey on Digital Agriculture in Five West African Countries. *Agriculture*, 13(5), 1067.

- Doody O, Doody CM. *Conducting a pilot study: case study of a novice researcher*. Br J Nurs. 2015 Nov 26-Dec 9;24(21):1074-8. doi: 10.12968/bjon.2015.24.21.1074. PMID: 26618678.
- Ehui, S. (2016). *How can we help Smallholder Farmers Seize Opportunities in Africa?* World Bank Blogs. <https://blogs.worldbank.org/africacan/how-can-we-help-smallholder-farmers-seize-opportunities-in-africa>
- Elmendorp, R. (2021, July 26). *Cryptocurrency booming among Kenyan farmers*. VOA. <https://www.voanews.com/a/africa-cryptocurrency-booming-among-kenyan-farmers/6208732.html>
- Fabregas, R., Harigaya, T., Kremer, M., & Ramrattan, R. (2022). *Digital Agricultural Extension for Development. Introduction to Development Engineering: A Framework with Applications from the Field* (pp. 187-219). Cham: Springer International Publishing.
- Farmerline (2023). *Leaving no farmer behind!* <https://farmerline.co/leaving-no-farmer-behind/>
- Fraenkel, J. R., Wallen, N. E., & Hyun, H. H. (2012). *How to design and evaluate research in education* (Vol. 7, p. 429). New York: McGraw-hill.
- Gay, L. R., & Mills, G. E. P. Airasian (2009). *Educational Research: Competencies for analysis and application-9th. Ed.* New Jersey: Merril-Pearson Education.
- Global Agriculture and Food Security Program. (2018). *Technology connects Kenyan smallholders with Market Access*. <https://www.gafspfund.org/projects/technology-connects-kenyan-smallholders-market-access>
- Gullickson, G. (2019, December 2). *How automated guidance changed farming*. Successful Farming. <https://www.agriculture.com/crops/how-automated-guidance-changed-farming#:~:text=Automated%20guidance%20also%20enables%20farmers,marketing%20manager%20at%20Precision%20Planting>.
- Hazell, P. and Wood, S. (2008) Drivers of change in global agriculture. *Philosophical Transactions of the Royal Society B*, 363, 495-515
- Hertzog, M. A. (2008). Considerations in determining sample size for pilot studies. *Research in nursing & health*, 31(2), 180-191.
- Holland, H., & Linvill, J. (2019, August 19). *Important considerations for protecting human research participants*. Purdue University. <https://www.purdue.edu/research/dimensions/important-considerations-for-protecting-human-research-participants/>

- Ismail, I. J. (2023). *Seeing through digitalization! The influence of entrepreneurial networks on market participation among smallholder farmers in Tanzania*. The mediating role of digital technology. *Cogent Food & Agriculture*, 9(1), 2171834.
- Janzen, S., Magnan, N., & Mullally, C. (2020). *Assessing the impact of digital loans for agriculture in Kenya*. Assessing the Impact of Digital Loans for Agriculture in Kenya. <https://basis.ucdavis.edu/project/assessing-impact-digital-loans-agriculture-kenya>
- Javaid, M., Haleem, A., Singh, R. P., & Suman, R. (2022). Enhancing smart farming through the applications of Agriculture 4.0 technologies. *International Journal of Intelligent Networks*, 3, 150-164.
- Kaiser, K. (2009). Protecting respondent confidentiality in qualitative research. *Qualitative health research*, 19(11), 1632-1641.
- Kalele, D. N., Ogara, W. O., Oludhe, C., & Onono, J. O. (2021). Climate change impacts and relevance of smallholder farmers' response in arid and semi-arid lands in Kenya. *Scientific African*, 12, e00814.
- Kimoni, M. N., Nzengya, D. M., & Nzeve, J. K. (2022). Smallholder Farmers' Perception, Level of Awareness and Adaptation to Climate Change in Masinga Sub County, Machakos County, Kenya. *African Multidisciplinary Journal of Research*, 159-172.
- Kiplimo, J. C., Ngenoh, E., Egerton, K., & Bett, J. K. (2015). Evaluation of factors influencing access to credit financial services: evidence from smallholder farmers in eastern region of Kenya. *Evaluation*, 6(17), 1-11.
- Kirui, O. K., Okello, J. J., & Nyikal, R. A. (2010). Awareness and use of m-banking services in agriculture: The case of smallholder farmers in Kenya.
- Kuisma, T., T. Laukkanen, and M. Hiltunen, "Mapping the reasons for resistance to internet banking: a means-end approach," *International Journal of Information Management*, Vol. 27, No. 2: 75-85, 2007.z
- Kumar, Praveen and Turnbull, Stuart M. "Patenting and licensing of financial innovations", Working paper, CT Bauer College of Business, University of Houston, July. (2006)
- Lambon-Quayefio, M., Manjeer, U., & Udry, C. (2019). *Assessing the impact of digital loans for agriculture in Kenya*. Assessing the Impact of Digital Loans for Agriculture in Kenya. <https://basis.ucdavis.edu/project/assessing-impact-digital-loans-agriculture-kenya>
- Langyintuo, A. (2020). Smallholder farmers' access to inputs and finance in Africa. *The Role of Smallholder Farms in Food and Nutrition Security*, 133-152.
- Mann, L. (2021, April 13). *The phantomization of rural Kenya is reshaping power within agricultural production networks*. Africa at LSE.

<https://blogs.lse.ac.uk/africaatlse/2021/04/01/platformisation-digital-rural-kenya-reshaping-the-balance-of-power-agricultural-production-networks-app/>

- Marshall, P. A., Adebamowo, C. A., Adeyemo, A. A., Ogundiran, T. O., Strenski, T., Zhou, J., & Rotimi, C. N. (2014). Voluntary participation and comprehension of informed consent in a genetic epidemiological study of breast cancer in Nigeria. *BMC medical ethics*, *15*(1), 1-11.
- Marwa, M. E., Mburu, J., Elizaphan, R., Oburu, J., Mwai, O., & Kahumbu, S. (2020). Impact of ICT based extension services on dairy production and household Welfare: the case of iCow service in Kenya. *J. Agric. Sci*, *12*(3), 1-12.
- McFadden, J., Njuki, E., & Griffin, T. (2023). Precision Agriculture in the Digital Era: Recent Adoption on US Farms.
- Misaki, E., Apiola, M., Gaiani, S., & Tedre, M. (2018). Challenges facing sub-Saharan small-scale farmers in accessing farming information through mobile phones: A systematic literature review. *The Electronic Journal of Information Systems in Developing Countries*, *84*(4), e12034.
- Muatha, I. T. (2014). *An analysis of farmers awareness of agricultural extension devolution and preferences for participatory design of agricultural extension programs in Kenya* (Doctoral dissertation, University of Nairobi).
- Mugo, M. (2019). *Digital Input Loans for Smallholders – how can providers optimize uptake and repayment?* Mercy Corps AgriFin. <https://www.mercycorpsagrifin.org/2019/10/07/digital-input-loans-for-smallholders-how-can-providers-optimise-uptake-and-repayment/>
- Mugunieri, G. L., & Omiti, J. M. (2007). In *Decentralization and the social economics of development: lessons from Kenya* (pp. 64-83). Wallingford UK: CABI.
- Musyoka, H. J. (2017). *Influence of socio-economic status on the access to agricultural farm inputs by small holder farmers in Yatta sub-county of Machakos county, Kenya* (Doctoral dissertation, University of Nairobi).
- Mutiga, M. W. (2015). *The role of farming mobile applications in community development* (Doctoral dissertation, University of Nairobi).
- Mwangi, V., Owuor, S., Kiteme, B., & Giger, M. (2021). Assessing Smallholder Farmer's Participation in the Wheat Value Chain in North-West Mt. Kenya. *Frontiers in sustainable food systems*, 198.
- Ndimbo, G. K., Yu, L., & Ndi Buma, A. A. (2023). ICTs, smallholder agriculture and farmers' livelihood improvement in developing countries: Evidence from Tanzania. *Information Development*, 02666669231165272.

- Ngele, J. M. (2015). *Impacts Of Demand Driven Agricultural Extension Services On Maize Production And Soil Conservation Among Small Scale Farmers In Moiben Sub-County, Uasin Gishu County, Kenya* (Doctoral dissertation, University of Eldoret).
- Odhiambo, F. O., & Upadhyaya, R. (2020). Flexible loans and access to agricultural credit for smallholder farmers in Kenya. *Agricultural Finance Review*.
- Onsomu, E., Munga, B., Munene, B., Macharia, J., & Nyabaro, V. (2022). Disruptive Technologies, Agricultural Productivity and Economic Performance in Kenya.
- Ozili, P. K. (2018). Impact of digital finance on financial inclusion and stability. *Borsa Istanbul Review*, 18(4), 329-340.
- Parlasca, M. C., Johnen, C., & Qaim, M. (2022). Use of mobile financial services among farmers in Africa: Insights from Kenya. *Global Food Security*, 32, 100590.
- Pauschinger, D., & Klauser, F. R. (2022). The introduction of digital technologies into agriculture: Space, materiality and the public–private interacting forms of authority and expertise. *Journal of Rural Studies*, 91, 217-227.
- Pazarbasioglu, C., Mora, A. G., Uttamchandani, M., Natarajan, H., Feyen, E., & Saal, M. (2020). Digital financial services. *World Bank*, 54.
- Pennings, Johannes M. and Harianto, Farid. “The diffusion of technological innovation in the commercial banking industry”, *Strategic Management Journal*, 13.1 (1992):29 – 46.
- Poon, W. C., “Users’ adoption of e-banking services: The Malaysian perspective,” *Journal of Business and Industrial Marketing*, Vol. 23, No. 1: 59-69, 2008.
- Prachi Singh, and Yangson Bao, “*Hyperspectral Remote Sensing*”, 2020
- Rajkhowa, P., & Qaim, M. (2021). *Personalized digital extension services and agricultural performance: Evidence from smallholder farmers in India*. *Plus one*, 16(10), e0259319.
- Rao, P. (2018). *Africa could be the next frontier for cryptocurrency |Africa Renewal*. United Nations.
- <https://www.un.org/africarenewal/magazine/april-2018-july-2018/africa-could-be-next-frontier-cryptocurrency>
- Rapsomanikis, G. (2015). *The economic lives of smallholder farmers: An analysis based on household data from nine countries*. Food and Agriculture Organization of the United Nations, Rome.
- Rogers, E. M. (1962). *Diffusion of innovation*. New York: Free Press.