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# E-Agriculture Framework to Improve Agricultural Productivity: Literature Review

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## Abstract

The agricultural sector is increasingly becoming knowledge-intensive as farm automation is significantly improving the productivity of these farms. High-tech developments in agriculture offer vast possibilities for entrepreneurs, agriculturalists, and investors to ameliorate the productivity and efficiency of agriculture at a time when several issues, such as drought, emerging diseases, fertilizer dependency, and global warming, are threatening food security. While there have been significant innovations and increased adoption of ICTs in agriculture, it is arguable that this has not been reflected in agricultural productivity as much. In improving agricultural output, farmers need access to timely, accurate, relevant, and consumable information in relation to their farming activities. In this regard, this paper seeks to identify and demonstrate the role of digital applications in improving agricultural productivity and output, and to review the E-agriculture frameworks supporting the design and development of these digital solutions for improving agricultural productivity.

## Keywords

ICT-in-Agriculture, Innovation, Technology Adoption, Farm Productivity, E-Agriculture Framework

## 1. Introduction

According to the (FAO, 2018), the global population is expected to grow to at least 9.5 billion by 2050 and as such, there is need to improve food security and productivity to support this population. In achieving this, we need deliberate actions towards providing and meeting the information needs of the farmers and supporting the farmers to learn and adopt new and emerging farming techniques and technologies (World Bank, 2016). This will also mitigate the low

productivity in the agricultural sector that has been accelerated by the absence of technological proficiency, climate change, and the relocation of youths from the countryside to towns and cities, particularly in developing nations.

Recently, the adoption of technology in agriculture has significantly increased agricultural productivity (Bruinsma, 2017). These technologies, including digital tools and their innovation, such as aerial imagery, drones, and satellites, sensors, the internet of things, mobile applications among others have automated farming and transformed it into a data-driven industry as farmers can now manage their farms and cropping activities on real-time and with much ease. Technological advancements in the agricultural sector have empowered agriculturalists, businessmen, and investors to extend their potential in delivering agricultural activities during a time when food security is being threatened by climate change and population growth (KARLO, 2017). Evidently, increased mechanical automation, the extensive utilization of pesticides and fertilizers, stressing the importance of industrial farming and soil management have made agricultural production possible at a time when farms and the number of farmers are steadily diminishing (Pivoto, 2018).

The information and communication technology (ICT) is fundamental in the dissemination of agricultural information. ICT enables the collection and sharing of accurate and timely information in relation to farmers' needs, and in a format that is easily accessible and consumable by the farmers, for instance on weathercast, market and pricing, financial access and support, etc. Essentially, ICT enables the dissemination of knowledge to farmers and connects various stakeholders and members of the value-chain in agriculture such as the farmers and consumers, agricultural financial and credit facilities, agricultural research institutions, policymakers, agricultural input manufacturers, agricultural training, support, and extension service providers among others. The applications of ICT in agriculture have ranged from supporting land preparations, planting and the pre-harvest activities, harvest operations, and post-harvest activities including market access and yield preservation in reference to cropping (An exhaustive discussion of ICT applications in cropping and animal production can be found in (FAO, 2018; Evenson & McKinsey, 2019; Anyan & Frempong, 2018).

The review is of relevant literature on ICT in agriculture solutions, architectures and frameworks retrieved from publication databases using Google scholar search engine composed of books and book chapters, journals and conference proceedings. The information and data collected from these source were synthesizes towards addressing the objectives. For the sake of clarity, the term e-agriculture framework is used to refer to blueprint or basic structure underlying the various applications of ICT in agriculture.

## 2. Problem Definition

Research has demonstrated that there are several aspects that influence farmers' utilization of information, they include but are not limited to age, one's educa-

tion, involvement in agricultural activities; business characteristics such as the market orientation of agriculture, farm proportions, type of agricultural holdings such as level of debt, distance from the market and the nearest technological centers (Baumüller, 2018). According to Mittal, Gandhi, and Tripathi (2010), for successful supply of inputs through ICT, then education and knowledge on information dissemination were important. On a more practical level, farmers need a good understanding of the potential long-term consequences of using better inputs for productivity.

While there have been significant innovations and increased adoption of ICTs in agriculture, so-called E-agriculture, it is arguable that this has not been reflected in agricultural productivity as much (Awuor, Raburu, Onditi, & Rambim, 2016). This has been owed to a number of reasons. Firstly, the development of these applications does not always involve the farmers and as such do not reflect and accommodate the intended users need, that is the farmers, are good or bad in, or their user profiles such as language barriers (FAO, 2015). Secondly, the design and development of these E-agriculture solutions do not consider the divides that ordinarily bar the farmers from accessing and using these applications such as the technology divide, gender divide, illiteracy, etc (Awuor, Raburu, Onditi, & Rambim, 2016). Thirdly, these applications are also reported not to be inclusive and to leave out users such as those with disabilities (Singh & Sohane, 2016). Fourthly, these applications are costly to acquire and sustain as they required subscriptions fee, access to the Internet, and airtime on the phone to leverage them (FAO, 2009). Evidently, there is a need for a review of the guidelines, so-called frameworks that lay the foundation and support the development of these E-agriculture applications. To this end, the aim of this paper is to provide a review of these E-agriculture frameworks in the context of their support in the design, development, and adoption of E-agriculture applications. Specifically, the objectives of this paper are to:

1) Demonstrate the role and place of ICT applications in improving agricultural productivity and output.

2) Review and analyze e-agriculture frameworks leveraged in the design and development of ICT applications towards improving agricultural productivity.

Therefore, the contribution of this paper is to explore the available design frameworks for developing e-agriculture applications and to demonstrations their operationalization.

## 3. Role of ICTs in the Agricultural Sector

Smallholder farmers' income can be enhanced through the expansion of agricultural produce, which is a critical aspect of reducing poverty, especially for those that do not have enough resources to influence the growth and marketing of their farm produce. For this to be realized, there has to be an effective and well-organized value chain that ensures that all farmers' and stakeholder needs ranging from farming activities, supplies, and distribution of products are taken

care of. However, the effective and systematic flow of valuable information is dependent on the availability of an efficient and reliable ICT infrastructure and associated services to link to a variety of stakeholders along the agricultural value chain (Halewood & Surya, 2012). In this sense, ICTs offer exceptional opportunities to facilitate agricultural-related technical information on markets, weather conditions, transportation, and farming methods. The concept of ICT in this paper refers to Information and Communication Technologies including but not limited to phones, computers, Internet, TVs and Radios, Robots, etc.

It's been shown through theoretical and empirical literature on developing countries that ICTs have significantly increased access to financial resources, hence, reducing the poverty while economically empowering the farmers (Burgess & Pande, 2005; Conceição, et al., 2016). For instance, studies have shown that households in Kenya using mobile money transfer M-Pesa have better managed negative life encounters such as poor harvests, death of livestock, and loss of jobs (Aker & Mbiti, 2010; Sen & Choudhary, 2011). The mobile money system in the continent of Africa is progressively maturing and now services such as insurance, saving and credit facilities have been provided to smallholder farmers whose crops have failed, positively impacting the lives of these farmers (Sen & Choudhary, 2011).

The use of ICTs can facilitate the adaptation of agricultural practices by researchers and extension officers resulting in the dissemination of relevant information and practices to smallholder farmers. Information such as farming methods, prices of produce, and information regarding the weather patterns can be provided to farmers (Aker & Mbiti, 2010). For instance, mobile technologies have assisted farmers to know the average market prices of their commodities when compared to prices of adjacent markets, and the time and place to sell their products most efficiently at a better economic advantage or gain. In the event this information changes or is misrepresented by middle traders, when there are serious agricultural consequences leading to the fluctuation in market prices and supply of produce. Mobile technological advances have enabled farmers in rural Africa to change their conditions, for example, the use of e-Soko in Rwanda has enabled farmers to compare market prices for the crops they produce, while those engaged in fishing are able to sell their fish directly to their clients every day, thus reducing spoilage and wastage of their catch (Aker & Mbiti, 2010; Chavula, 2014).

## 4. Improving Productivity in Agriculture Using ICTs

It has been proved through research that using ICT in accessing commodity price information increased 36% of both farmers' and traders' income in developing countries such as Morocco, Kenya, Uganda, and Ghana (Halewood & Surya, 2012). The reason for this is that ICTs enable a fast and efficient exchange of information between sellers and buyers leading to reduced communication costs, thereby enabling markets to operate more efficiently (Aker & Mbiti, 2010).

Consequently, a production increase is witnessed in the agricultural sector, and the country's economy in total.

ICT has facilitated farmers' real-time access to crucial market and price information thereby playing a crucial role in agricultural growth and development. The use of the internet and web portals has further enabled farmers to trade online through their mobile phones applications or web platforms (Driouchi & Zouag, 2010). Farmers can now receive information instantly and on a regular basis, unlike other traditional communication methods. It has been demonstrated that the use of mobile ICTs has significantly lowered search costs as postulated by search theory. It has been said that mobile ICT technologies have empowered consumer welfare by enabling them to disrupt the monopoly power of most traders and middlemen, thereby producing a counter effect of reducing the traders' welfare (Aker & Mbiti, 2010). Similarly, mobile ICTs might have an initial high cost that is fixed, but the associated benefits and opportunities that are realized during their use are far much lower than associated logistic and opportunistic costs.

Aker and Mbiti (2010) conducted a study in Niger where they observed a two-minute phone-call was economical and would save an average 2-to-4-hour roundtrip of 65 km away from the market. E-Soko an online agricultural marketing and messaging service in Ghana that facilitates market data and other information to individuals, agribusinesses, and government agencies by text messaging services and personalized alerts inter alia, managed to increase the revenue by 10% to farmers as soon as they began utilizing platform (Halewood & Surya, 2012). The presence of real-time market dynamics enabled by ICTs has enhanced the capturing of products' value. A study conducted by Muto and Yamano (2019) revealed that the use of mobile devices increased the probability by 10% of market participation by banana farmers and not maize farmers, suggesting that mobile technology is instrumental in managing perishable farm produce. Supporting the idea that ICTs in agriculture has the capability of improving economies of countries through improved yields, access to market information, etc., and consequently the livelihoods of farmers, particularly linking farmers and agricultural information on things to deal with money, pest control and management, weather forecasting and pattern, and crop management. For instance, the people of Ethiopia through the Ethiopian Commodity Exchange have been provided with a virtual marketplace that allows the farmers to access all information that deals with the supply, demand, and prices of farm produce, thereby increasing the revenue of farmers (Evenson & McKinsey, 2019).

## 5. E-Agriculture Framework towards Improving Agricultural Productivity

### 5.1. E-Agriculture Framework—Definition and Structure

According to (FAO, 2009), E-agriculture is an evolving field that can be described as tools that digitally collect, store, analyze and share electronic data and

information in agriculture. These data collected intersect from different fields such as technology, agricultural services, entrepreneurship, and agricultural informatics ensuring that agricultural services and information are disseminated efficiently through the Web and other related technologies. The E-agriculture community will have the following group of persons; researchers in both agriculture and ICT matters, farmers, various service providers, policymakers, and development experts. More precisely, it entails innovatively using available ICT technologies and adapting new technologies in the conceptualization, designing, developing, and evaluation of new agricultural digital tools (Singh & Sohane, 2016) to be used primarily and extensively for agricultural purposes in remote or rural places (Birthal, 2013). According to (Amadu, McNamara, Davis, & Rodriguez, 2015; Wyche & Steinfield, 2015), the utilization of ICT in agricultural-related research and development can be grouped into the following categories;

- Data collection—Capability of collecting both agricultural and environmental data from various sources without any human intervention. The data collected is consequently analyzed and manipulated and fed into an auxiliary application to conduct studies.
- Number crunching—Capability of processing numerical data organizing it to a more useful format for simulation and modeling, digital image processing, and visualization to contribute to plant and animal breeding, animal epidemiology, farming research, market analysis, and bioinformatics among others.
- Geo-spatial applications—Capability to store, process, and provide access to visualized geospatial data that can be utilized for land and water planning, the use of natural resources, mapping of poverty and hunger, and the supply of agricultural inputs.
- Decision support and knowledge-based systems and robotics—Capability to collect and analyze data from a variety of sources with the ultimate goal of providing users with insight into their decision-making process especially in searching for information, diagnosis, and automation of agricultural processes.
- Embedded ICT in farm equipment and processes—Capability to efficiently automatic farm equipment and agricultural processes with the use of technologies such as the Radio Frequency Identification (RFID) tags, traceability, identity preservation, Wireless Internet, and Cellular Telephony in cataloging.
- Connecting communities and enabling learning—Capability to link and connect farmers, researchers, and other stakeholder communities using ICT. Researchers and other scientists in the field of agriculture are also enabled to communicate with each other through scientific publications.

### 5.2. Need for E-Agriculture Frameworks

Information requirements and needs of farmers vary considerably within a

country and from country to country due to the fact that farmers have different perceptions of what information is useful for them and how they can access it. The fundamental message underscoring all these differences among farmers shows that the farmers' needs and priorities change throughout the production cycle (World Bank, 2011). Therefore, there is a need to engage all agricultural stakeholders during the process of integrating ICTs in agriculture.

The quality of information available to farmers has negatively impacted their capability to make informed decisions, and this is due to inconsistent data formats and standards. Well established frameworks such as the Knowledge Discovery in Databases have been successfully deployed in other fields and therefore relevant methodologies can too be applied in the agricultural sector – a framework that takes in farmer's needs in all their formats and ends up providing crucial information in the right format for consumption by the farmers (Anyan & Frempong, 2018). Before information is delivered to the farmer it has to be captured from different sources, thoroughly processed and analyzed using data mining technologies, then integrate to make it ready to be delivered to the farmer (Gandhi, & Armstrong, 2016).

Constant research needs to be directed at developing frameworks that enhance the understanding of farmers' informational sources. And because data is generated rapidly, there is an urgent need of developing new systems that will do the following; disseminate information after understanding the needs of the target community (Msoffe, & Ngulube, 2016), document and predict the information searching behavior of farmers (Mahindarathne & Min, 2018), considering social-economic influences that affect technology adoption (Lubua, 2022), or farm inputs (Kante, Oboko, & Chepken, 2019). For instance, Ahmad et al. (2020) utilized a framework that correlated livestock farmers to their social-economic characteristics. They postulated that there is a significant relationship between social-economic characteristics with effective information sources. Adoption of relevant technologies required for livestock production among farmers is ultimately affected.

### 5.3. E-Agricultural Frameworks on Improving Agricultural Productivity

ICT agricultural frameworks are farmer-centric portals that facilitate the exchange of information, ideas, and resources that are associated with sustainable agricultural practices. These frameworks are presented below:

- Framework on drought prediction—This framework, proposed by (Masinde & Antoine, 2010), and designed in partnership with agronomists, meteorologists, ecologists, hydrologists, and environmentalists was used to assist farmers in predicting drought. It leverages the mobile phone as the gateway, data mule and processor, and a device for the application input and output.
- Framework for agro-advisory services—This framework provides a strategy to collect and share with the farmers' information on crop management practices, monitoring crop health, and crop pest and disease surveillance and

monitoring Gangopadhyay, Khatri-Chhetri, Shirsath, and Aggarwal (2019).

- Farmer-centered e-agriculture framework is formulated on the premise that while developing ICT applications in agriculture, it is important to actively engage all the stakeholders and have their concerns considered in the design and development of the applications (Awuor, Raburu, Onditi, & Rambim, 2016). This approach is argued to promote the adoption of these applications.
- Framework for engaging youth in agriculture—While farming has mostly been abandoned by the youths in developing nations, this framework proposes a mechanism to involve and engage the youth in agriculture Lohento and Ajilore (2015). It presents strategies to entice youths to consider agriculture as a potential employment avenue.
- Framework for agriculture information dissemination system—This framework defines a strategy to enable the extension service providers to reach out and support the farmers with the aim of establishing interactions among the following entities; research centers, agricultural experts, agricultural extension officers, farmers, and the community, Ommani, and Chizari (2008). An improvement of this framework is proposed by FAO (2018) that is aimed to improve facilitate communication between farmers, fields assistants, and policymakers leveraging mobile phones. In this design, farmers receive agriculture advisory messages in both text and voice.
- Framework for value addition and productivity differentials—This framework proposed by (Adeyemo & Okoruwa 2018) is designed to enable the farmers to predict the expected increase in productivity given their decisions to add value to their cropping activities.
- Tomato expert system framework—This framework proposed by Dubey, Pandey, & Gautam (2013) provides a general guideline for building crop diagnosis solutions leveraging advancements in technology such as machine learning and artificial intelligence. It also provides a foundation for building digital crop pest and disease surveillance and monitoring applications.
- Framework of ICT for disseminating agriculture-related information—This framework is a structure for building and developing agricultural information hub for training and learning purposes for the farmer (Singh, Ahlawat, & Sanwal, 2017). The framework proposes digital interactive multimedia approaches to design agricultural education materials, and how to provide ease of access to agricultural information. This is similar to the information dissemination framework for farming communities proposed by (Tantisantisom, 2011) which provides wide-reaching and ranging agricultural information to farmers.
- Cropping system framework—The cropping system framework proposed by (Jones et al., 2003) enumerated gender, age, education level, income, age, level of education, income, size of the farm, membership of a cooperative, and family size as social-capital and personal issues that influenced the adoption of ICT based market information.

- Integrated livestock framework—This framework was proposed by (Thornton & Herrero, 2001), and it utilized simulation and optimization tools to visualize the various interactions that are involved in livestock farming. For example, the tool could not compute grazing management strategies independently without considering other supplementary and complementary practices of the systems such as herd and nutrition management, grazing intensity, and the use of forage (Thornton & Herrero, 2001).
- ICT-based market information—This framework was proposed by Nwafor (2020) enabled one to view a visualization of important contributors who greatly influenced the adoption of ICT-based information that guides farmers in finding answers to their needs and questions. This framework demonstrated that for technology to be adopted by farmers then having a positive attitude towards technology and its likelihood of the information they receive help them in addressing their problems. A variant of this framework that seeks to improve the adoption of ICT tools to access farm inputs and access information in that relation is proposed by Kante, Oboko, and Chepken (2019).
- Video conferencing service model for farmers—This framework uses the Internet to achieve real-time video and voice communications towards supporting the agricultural experts to provide personalized and individualized attendance to farmers and train the farming community (Huber et al., 2018).

## 6. Discussion and Conclusion

Farmers have not been capacitated to make informed decisions due to inconsistent and inapplicable data that is provided to them. This poor-quality data that is inappropriate for farmers' consumption lacks standards that ensure that data integration and formatting. These have been exacerbated by them not getting relevant and appropriate data for their daily consumption. Various frameworks for the adoption of ICT in agriculture have been developed to ensure that the ICT in agriculture applications meets the needs of the farmers with regard to access to relevant, accurate, and timely information.

The design and implementation of appropriate policies and regulations are among the key ICT enabling interventions that may guide a country's investment in technological infrastructure, tools, and services. A conducive pro-ICT innovation environment supports the development of policies and regulations that boost and support vital events such as intellectual property and innovation, financing of infrastructure by both public and private institutions (Dlodlo & Kalezhi, 2015). To strengthen this field and ensure that there is a good investment in the private sector, then, strong yet flexible regulations and policies are supposed to be established.

The use of ICT tools to disseminate information between farmers and agricultural experts will bridge the existing gap that exists between these entities and further resolve many other agricultural barriers. For instance, the use of mobile

phones to inform farmers in remote areas will work more to impact the farmers, as compared to the use of telephone landlines which would require farmers to be connected by telephone lines. Moreover, the use of advanced technology such as video conference or voice over IP to transmit information between farmers and agricultural experts will lead to reduced traveling costs to reach the farmers in their remote locations, and also reduce the amount of time spent interacting with them (Awuor, Raburu, Onditi, & Rambim, 2016).

In view of the fact that ICT extension services deliver numerous essential benefits when compared to traditional methods of communication, these ICT services however come up with a myriad of challenges which include; a lack of technological infrastructure in rural areas, huge amount of capital required to set up and support these technologies, complexities when trying to integrate the existing technologies with the traditional methods of communication, and the lack of coordination and involvement of all stakeholders in fundamental organizational processes (Asenso-Okyere & Mekonnen, 2012).

The impedance to the adoption and usage of ICTs in improving agricultural productivity and output revolves around the involvement of the farmers in the development of these ICT-based agriculture solutions. This makes it difficult for the farmers to trust these solutions and the information they provide and as such do not ripe the benefits endowed in them. For instance, most of these digital agriculture solutions are unable to break the language barriers and provide their services in the farmers' local language. In this regard, this paper provides a review of frameworks that seek to provide a structure for designing and developing E-agriculture solutions that are usable and adoptable by farmers, particularly in developing nations. The paper also demonstrates the need and importance of ICT-based agricultural applications in improving farming and cropping output. This paper has leveraged existing literature to demonstrate the existing e-agriculture frameworks and their general role towards improving agricultural productivity. To build on this, future work might consider evaluating some of these frameworks to exhibit operationalization and thus their performance bounds.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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