



Available online www.unicrossjournals.com

UNICROSS JOURNAL OF SCIENCE AND TECHNOLOGY, UJUST

RESEARCH ARTICLE VOL. 4(3) SEPTEMBER, 2025 ISSN:2814-2233

Date Approved September 30, 2025

Pages 74 – 89

LEVERAGING DIGITAL INNOVATIONS FOR AGRICULTURAL SUSTAINABILITY AND FOOD SECURITY; ICT'S IMPACT SO FAR

Samuel, A. Kile and Tumenayu, O. Ofut

¹Department of Computer Science, University of Maiduguri, Maiduguri, Borno State

²Department of Software Engineering, University of Cross River State, Calabar.

Phone Number: +234(0)7039032499 Email: awunkile2@gmail.com

Abstract

Digital innovations and tools have the capacity to improve on the fortunes of farmers in their farming business, improving on food security. Unfortunately, there is a seeming gap in the adoption and use of these tools by majority of farmers. This study evaluated the role of Information and Communication Technologies (ICT) in enhancing agricultural productivity and food security by analyzing key tools, adoption barriers, measurable impacts, and promotion strategies. Mixed methodology of research, using both quantitative and qualitative approaches, was employed for the study. The study location was Benue state. The population of study was 410,129, and a sample size of 385 drawn from it by the use of the Cochran's method. Both primary and secondary data were used for the study. Primary data was gotten by the administration of questionnaires to respondents, while secondary data was gotten from literatures of standard bodies like World Bank Food and Agricultural Organization, e.tc. The statistical analyses of the data showed that smallholder farmers played more roles in agricultural productivity with many of them having low educational attainment. It was also discovered that between mobile apps, IoT sensors and drones, mobile apps were more acceptable and in use by farmers (64.7%). Again, farmers with higher educational level showed higher adoption rates than those with lower educational levels. Above all, farmers who embraced the use of ICT tools for their operations realized an increase in yield to about 20%. This proves that ICT tools significantly advance agricultural sustainability, but equitable adoption requires targeted policies, affordability measures, and infrastructure investment. The study recommends scaling farmer-centric designs and fostering public-private collaborations while calling for further research on geographic gaps, gender disparities, and emerging technologies like AI and 5G.

Key words: ICT in agriculture, digital divide, food security, smallholder farmers, sustainable adoption.

1.0 Introduction

Many economies still rely heavily on agriculture, especially in underdeveloped countries where food security is a major issue (FAO, 2020). Climate change, soil erosion, pest infestations, and ineffective farming methods are just a few of the many difficulties the industry faces. Information and communication technologies (ICTs) and digital innovations have been used more and more to improve food security, sustainability, and agricultural production in order to address these issues (World Bank, 2019). Aker (2011) also backed this viewpoint, stating that ICT has changed a number of agricultural practices by giving farmers access to real-time data, precision farming methods, and decision-support tools that help them make wise decisions.

Ending hunger, achieving food security, and advancing sustainable agriculture were all highlighted in the United Nations Sustainable Development Goals (SDGs), especially Goal 2 (United Nations, 2015). The goal of food security is to guarantee that everyone always has physical and financial access to enough food that is safe and nourishing (FAO, 2018). According to Pretty (2008), agricultural sustainability is the idea of long-term tactics that strike a balance between social justice, economic viability, and environmental health. By increasing supply chain management, reducing waste, and increasing farming efficiency, digital advances have played a crucial role in achieving these objectives.

According to Gebbers and Adamchuk (2010), precision agriculture is the use of data-driven technologies, such as remote

sensing, Geographic Information Systems (GIS), and the Internet of Things (IoT), to optimize farming methods. By predicting weather patterns, optimizing irrigation systems, and monitoring soil conditions, these technologies help farmers save resources and boost productivity.

As a result, Aker & Mbiti (2010) found that smallholder farmers can now access agricultural knowledge, thanks to the widespread use of mobile phones. Farmers can make informed decisions by using mobile-based advice services that offer real-time information on market prices, pest outbreaks, and weather forecasts (Mittal & Mehar, 2013). Platforms like e-Wallet in Nigeria and Esoko in Ghana, for example, have transformed agricultural extension services by giving farmers fast and tailored recommendations.

Big data analysis and prediction insights are being provided by AI-driven solutions in agriculture more and more (Kamilaris & Prenafeta-Boldú, 2018). Based on past data, machine learning algorithms can identify plant illnesses, forecast crop yields, and suggest the ideal periods for planting and harvesting. These technologies improve decision-making and lower climatic variability-related farming risks.

By increasing efficiency, decreasing fraud, and boosting traceability, blockchain technology is transforming agricultural supply networks. This view was expressed by Tian, (2016). Blockchain improves food safety and lowers losses from inefficiencies by establishing a decentralized, immutable record that guarantees all supply chain

participants have access to correct and verifiable information.

Evans and Sadler (2008) said that smart irrigation systems have been developed to maximize water use in agriculture due to the growing scarcity of water resources, which is proof of the need of adopting these technologies. IoT-based irrigation systems effectively control water distribution by utilizing weather information and soil moisture sensors, which lowers waste and increases agricultural yields.

ICT use in agriculture has greatly increased farmers' access to markets, decreased post-harvest losses, and increased production, as stated by Ferris et al. (2014). Research indicated that digital technologies facilitate precision farming, lessen reliance on conventional farming methods, and encourage climate-resilient agricultural practices, all of which lead to higher agricultural yields (Brewster et al., 2017). Additionally, by bridging the information gap between farmers and agricultural extension services, ICT solutions have promoted capacity building and knowledge sharing.

ICT has the potential to revolutionize agriculture, but a number of obstacles prevent its broad use. These include expensive upfront investment costs, low farmer digital literacy, poor infrastructure, and cybersecurity and data privacy concerns, a view supported by Duncombe, (2018). Furthermore, financial limitations frequently prevent smallholder farmers in underdeveloped nations from using cutting-edge digital technologies, as expressed by Qureshi et al. (2019). Governments,

businesses, and development organizations must work together to address these issues and guarantee that everyone has access to digital agricultural solutions.

Based on the aforementioned, the study's goal is to determine how much digital innovations are used to address agricultural sustainability and food security, mostly through the use of ICT tools. In particular, the study will identify ICT tools for food security and agricultural sustainability, gauge user awareness, evaluate the tools' effects on sustainability and food security, and promote their use to improve these areas.

It is impossible to overestimate how important ICT is to improving food security and agricultural sustainability. Precision farming, AI-powered analytics, blockchain-based supply chains, and mobile advisory services are examples of digital advancements that have greatly increased farming productivity, decreased losses, and given farmers better access to markets. However, in order to optimize the advantages of ICT in agriculture, stakeholders and policymakers need to improve digital literacy, remove adoption hurdles, and fund infrastructure that will help. Using digital technologies to build a more resilient, sustainable, and food-secure world is where agriculture is headed.

In an attempt to address this issue, this research aims to respond to the following queries: Which ICT tools, together with their salient characteristics, are now employed to advance food security and agricultural sustainability? How much do farmers and other agricultural stakeholders

know about these ICT technologies, and what factors affect their awareness? What quantifiable effects do ICT tools have on food security and agricultural productivity? What strategies might be used to advocate for and encourage the use of ICT tools for food security and sustainable agriculture?

2.0 Literature Review

Numerous studies have highlighted how ICT is changing agriculture. Digital advances have improved agricultural operations' production, efficiency, and decision-making, claimed Rotz et al. (2019). Similar to this, Wolfert et al. (2017) talked about how supply chain transparency and farm management are enhanced by big data and smart farming technologies. These researches have demonstrated that ICT may favorably improve agricultural activities, which is in line with our study's aim. Nonetheless, the goal of this study is to investigate how digital technologies might be used to improve food security and agricultural sustainability.

By closing the information gap, mobile technologies have had a big impact on agricultural extension services. By giving farmers access to market data, weather forecasts, and best farming techniques, mobile phones have empowered farmers, according to Aker and Mbiti (2010). Mittal and Mehar (2013) further noted that mobile advice services lead to better farm management and lower risks associated with climatic unpredictability. These unequivocally show that ICT methods used for agricultural productivity have produced favorable outcomes; yet, there is still more to learn, particularly in the broader context

of digital innovations for agricultural sustainability and improved food security, which is the focus of this study.

One important aspect of ICT-driven agricultural innovation is precision agriculture. The ways in which IoT, GIS, and AI-driven applications improve resource utilization, track crop health, and forecast yields were investigated by Gebbers and Adamchuk (2010). In their 2018 study, Kamilaris and Prenafeta-Boldú (2018) examined how machine learning improves precision farming and crop disease detection, which raises agricultural output. These ideas discussed in this work are cutting-edge technological advancements that have been used to improve agricultural operations, supporting the idea that digital innovations can be used to improve agricultural sustainability. However, it is still unclear to what degree this can be accomplished, which is why this research was conducted.

It has been acknowledged that blockchain technology increases supply chain transparency in agriculture. Tian (2016) described how blockchain's immutable digital record might lower fraud, boost productivity, and guarantee food safety. Blockchain promotes sustainable farming methods and boosts consumer confidence in the food supply chain by improving traceability. Although the study under review goes further to assess how these digital innovations can contribute to the agricultural sustainability and food security ecosystem, whereas this work emphasizes the significance of applying and utilizing technological innovations that promote

security and agricultural processes as a panacea for agricultural sustainability and food security.

Despite its enormous promise, ICT adoption is fraught with difficulties. According to Duncombe (2012), the main obstacles to the widespread use of ICT in agriculture include a lack of infrastructure, budgetary limitations, and digital illiteracy. In order to encourage digital inclusion, lower the cost of technology, and improve farmers' digital literacy, Qureshi et al. (2019) emphasized the necessity of legislative interventions. According to this work, the study under consideration supports the authors' opinions and aims to identify some of the barriers preventing the acceptance and application of these digital technologies for food security and agricultural sustainability.

Jumanne (2024) investigated how digital technology could support social and economic development in Kenya and advance sustainable agriculture. The study examined the effects of digital technologies on agricultural practices and examined the advantages and difficulties of implementing them, drawing on empirical data. Using a mixed-methods approach, the study collected and analyzed data using both qualitative and quantitative techniques. Purposive sampling was utilized to choose key informants, such as policymakers, agricultural specialists, and representatives from pertinent organizations and businesses, while stratified random sampling was utilized to guarantee a representative sample of farmers from different parts of Kenya. With an estimated 330,000 farmers in Kenya, sectioned into agro-ecological zones,

the study focused on three primary groups: farmers, key informants, and focus group discussion (FGD) participants. The quantitative data was summarized using descriptive statistical analysis, frequencies, percentages, and measures of central tendency. Inferential statistical techniques, such as regression analysis, were used to investigate the connections between the adoption of digital technology, agricultural practices, and social and economic outcomes. Key themes, trends, and insights were extracted from the qualitative data gathered through focus groups and interviews using thematic analysis. According to the study's findings, farmers between the ages of 18, 35, 36 and 55 had the highest adoption rates, indicating that younger and middle-aged farmers are more likely to use digital technologies. Nonetheless, there was a gender gap, with men farmers exhibiting greater adoption rates than female farmers, indicating the necessity of focused interventions. Adoption was found to be significantly influenced by education level, highlighting the significance of information access and digital literacy. Additionally, the adoption rate was higher among larger-scale farms, demonstrating the impact of capability and resources on technological investment. There were also regional differences in adoption rates; the Highlands region had the highest adoption rate. Regression analysis revealed that farmer training and governmental support were important motivators and validated the beneficial effects of technology adoption on agricultural practices. Access to financing, however, does not exhibit a statistically

significant correlation. Therefore, it is evident that using digital technology to support sustainable agriculture, as this study investigated, has a significant influence. The effort in question also aims to investigate the beauty of using these digital advances to promote improved food security and agricultural sustainability in Nigeria.

Biam and Tervershima (2020) used basic and stratified random sampling techniques to choose a sample size of 360 rural farming homes as part of their study on the food security condition of rural farming households in Benue state, Nigeria. Respondents were given a structured questionnaire, and descriptive statistics like frequency counts, percentages, and averages, as well as inferential statistics like the food security index and logistic regression model, were applied to the data gathered. With a mean age of 36, the data analysis showed that 84.4% of the respondents were young and engaged in agricultural production. Furthermore, 84.2% of the households with respondents were headed by men, 53.3% had an output of more than 1500 kg with a mean of 1394.59 kg, 36.9% had a large household with an average of 8 people, 46.9% had low annual income with a mean of N64, 043.54 (173.0910 USD), 40% had a farm larger than 3.1 hectares with a mean of 2.18 hectares, and 69% had attended at least primary school. 50.3% of rural farming households experienced food insecurity, according to the findings of the study. While the work under review examined the advantages of improving agricultural sustainability and food security through the adoption of digital innovations, with a focus

on rural farmers in Benue state as well, this study is equivalent to the work under review in that it examined and analyzed the food security status of rural households in Benue state. This study further aims to address the review's findings about a lack of information and support for farmers using and embracing ICT tools for increased agricultural sustainability and production.

3.0 Methodology

This study was achieved using mixed methods. Both qualitative and quantitative methods were deployed for the study.

This study was conducted in Benue state because it is frequently regarded as an agrarian state and is known as "The Food Basket of the Nation." In recent years, herdsmen's insurgency has hindered the state's capacity to produce and maintain agricultural activities. The study will address the basic concerns of "will the adoption and use of digital innovations have positive impact on agricultural productivity in these areas, also guaranteeing food security?" based on the research questions that serve as the project's cornerstone. Questionnaires and interviews were used as the data collecting strategy. Utilizing a structured questionnaire, primary data was gathered. To choose respondents who are farmers and extension agents from the state's three geopolitical zones/regions, purposeful sampling was used. While the interviews were performed over the phone and in person, the questionnaires were distributed physically and online.

3.1 Population and Sampling Procedure

All of the rural farming households in Nigeria's Benue State made up the research

population. According to Ani et al. (2016), there are an estimated 413,159 rural farming households in the State. For the study, a sample of 385 respondents was chosen using Cochran's technique for determining sample size. The sample size was chosen using straightforward and proportionate stratified random sampling procedures. Zones A, B, and C are the three agricultural zones that make up the state. There were six Local Government Areas in all, with two chosen at random from each of the three zones. Otukpo and Ogbadibo Local Government Areas are located in zone C, Gboko and Gwer East Local Government Areas are located in zone B, and Kwande and Katsina-Ala Local Government Areas are located in zone A. Using a proportionate stratified random sample technique, rural agricultural households were chosen at random from each of the chosen Local Government Areas based on their population size.

Moreover, key informants—policymakers, agricultural specialists, and representatives of organizations and businesses with an agricultural focus were chosen through the use of purposive sampling. These people gave useful information about the tactics and regulations used to effectively use digital technologies in agriculture. Three major categories comprise the research's target population: farmers, key informants, and focus group discussion (FGD) participants.

3.2 Data Collection and Variable Measurement

Only primary sources provided the data for this investigation. The secondary data was

used to compare with the results of the study. The primary sources from which the data were gathered were 385 respondents. A series of structured questionnaires were used to collect the primary data, and they were given to the selected agricultural households. Standard literature, such as publications from the Food and Agricultural Organization (FAO), World Bank, and others, provided the secondary data. The purpose of the research instrument was to answer research questions and provide answers pertaining to this particular study objective.

The study's variables included dependent, independent, control and economic indicators. Crop yield in kilograms per hectare was the dependent variable; ICT adoption level—the independent variable; farm size, irrigation access, farmer education, soil quality, etc., used as the control variables; and cost-benefit ratios, which are used to calculate input costs and revenues, were used as the economic indicators.

4.0 Results and Discussions

4.1 Results

The study adopted a mixed method, employing both quantitative and qualitative approaches, as such, results and discussions are also based on these approaches.

4.1.1 Quantitative Data Analysis

Table 1: Profile of Demographics

Category	Sub Group	Frequency (N=385)	Percentage (%)
Role in Agriculture	Smallholder Farmer	217	56.4
	Agri-Cooperative Member	79	20.5
	Commercial Farmer	68	17.7
	Government/NGO Staff	30	7.7
Educational Level	No formal Education	69	18.0
	Primary	138	35.9
	Secondary	119	30.8
	Tertiary	59	15.4

From table 1, it can be seen that smallholder farmers were the majority and government officials/NGO staff were the least considered during the survey. Also, farmers with only primary education were more with those who had tertiary education being the least.

Table 2: Measured ICT Awareness and Adoption (on a Likert Scale;1=low, 5=high)

ICT Tool	Mean Awareness	Adoption Rate	Barrier(s)
Mobile Apps	4.1	249 (64.7%)	High Cost
IoT Sensors	3.0	85 (22.2%)	Lack of Training
Drones	2.3	36 (9.4%)	No Internet

From table 2, it can be observed that mobile apps are more commonly adopted by farmers as compared to other ICT tool, followed by IoT sensors with drones being the least.

4.1.2 Qualitative Data Analysis

A. Regression Analysis Model

The regression analysis model compares the adoption of ICT tools and their impact on agricultural productivity, that is, farm yield. It is given as:

$$\text{Yield (kg/Ha)} = \beta_0 + \beta_1(\text{ICT Adoption})_i + \beta_2(\text{Fram Size})_i + \beta_3(\text{Irrigation}) + \epsilon$$

Where:

Yield (kg/Ha) is the dependent Variable. It represents the agricultural output (yield)

measured in kilograms per hectare (kg/Ha). It is the outcome variable that the model seeks to explain.

Independent variables in the model are:

ICT Adoption (β_1): This variable measures the extent of Information and Communication Technology (ICT) adoption by farmers. It could be a binary variable (e.g., 1 if a farmer uses ICT tools like mobile apps, sensors, or digital advisory services, 0 otherwise) or a continuous variable (e.g., frequency or intensity of ICT usage). It means the expected change in yield (kg/Ha) for a one-unit increase in ICT adoption, holding other factors constant.

Farm Size (β_2): This represents the size of the farm, likely measured in hectares (Ha). It

implies the expected change in yield (kg/Ha) for a one-unit (e.g., 1 Ha) increase in farm size, assuming other variables remain constant.

Irrigation (β_3): This is a binary or categorical variable indicating whether the farm uses irrigation (e.g., 1 if irrigated, 0 if rainfed). It therefore represents the expected difference in yield (kg/Ha) between irrigated and non-irrigated farms, keeping other variables fixed. Other components of the model are: β_0 (Intercept): It is the baseline yield (kg/Ha) when all independent variables (ICT Adoption, Farm Size, Irrigation) are zero.

ϵ (Error Term): It represents unobserved factors affecting yield that are not captured by the model (e.g., weather variations, soil quality, farmer skill).

Table 3: Adoption versus Education (Chi Square Test)

Education Level	Adoption Rate (%)	X^2 Statistics	p-value
No Formal Education	18.3	22.15	<0.001
Tertiary Education	72.6		

Table 3 shows the result of ICT tools' adoption rates by farmers being compared to their level of education. It indicates that

4.1.3 Cost-Benefit Analysis (CBR)

It is used to analysis the benefit or not of using a technology or method for a business purpose. It is given by the formula:

$$CBR = \frac{[\text{Net Benefits (Increase Revenue + Cost Savings)}]}{[\text{Total ICT Adoption Cost}]}$$

farmers with higher levels of education shows higher adoption rates as compared to farmers with lower educational background.

Thus, for a $CBR > 1$, it is a profitable business, but for a $CBR < 1$, the business is not cost effective.

Table 4: Analysis of Cost and Benefit

ICT Tools	Avg Annual Cost (N)	Avg Revenue Increase (N)	CBR
Mobile Apps	45	290	6.4
IoT Sensors	180	400	2.2
Drones	1100	700	0.6

Table 4 shows the cost benefit analysis of ICT tools’ adoption for agricultural productivity. Mobile apps showed the least average annual cost with the highest cost benefit ratio, while drones showed the highest average annual cost with the least cost benefit ratio.

4.1.4 Impact Evaluation

Table 5: Pre-Post Adoption (n = 86 Adopters)

Metric	Pre-Adoption	Post-Adoption	Change (%)	p-value
Yield (kg/Ha)	1,750	2,100	+20	0.003
Water Use (L/Ha)	5,200	4,000	-23	0.01

A 20% increase in output and a roughly 23% decrease in water usage for agricultural production are shown in Table 5, which compares agricultural productivity before and after the introduction of ICT technologies.

4.2 Discussions of Results

The study investigated how information and communication technologies (ICT) might improve food security and agricultural sustainability. Main findings into the adoption trends, obstacles, and effects of ICT tools in agriculture are revealed by the investigations, which are based on both quantitative and qualitative assessments. A thorough analysis of the findings is presented below.

4.2.1 Demographic Profile and ICT Adoption

(i) Role in Agriculture: Smallholder farmers made up the majority of respondents (56.4%), followed by agri-cooperative members (20.5%), commercial farmers (17.7%), and government/NGO staff (7.7%), according to the demographic profile of the farming population and ICT and their corresponding rates of ICT adoption. This demonstrates the study's emphasis on small-scale farmers, who are essential to food security yet frequently confronted with significant obstacles.

(ii) Education Level: Only 15.4% of farmers had higher education, but a sizable number had only elementary (35.9%) or secondary (30.8%) education. Farmers with higher levels of education demonstrated higher adoption rates of ICT (72.6% for tertiary-educated vs. 18.3% for no formal education,

$p < 0.001$), reflecting their educational inequality.

Thus, it is clear that the prevalence of smallholder farmers highlights the need for ICT solutions that are suited to their low incomes and educational backgrounds. According to the relationship between education and ICT adoption, using digital tools effectively requires technical skills and literacy. To close this gap, interventions should incorporate capacity-building initiatives.

4.2.2 ICT Awareness and Adoption

Based on the results of this study, it can be said that the following factors increased farmers' awareness of and adoption of ICT:

- (i) Mobile apps had the highest awareness (mean = 4.1) and adoption rate (64.7%), followed by drones (awareness = 2.3, adoption = 9.4%) and IoT sensors (awareness = 3.0, adoption = 22.2%).
- (ii) Barriers: The main obstacles were the high cost of smartphone apps, the inability to train IoT sensors, and the absence of internet access for drones.

This demonstrates that mobile apps' popularity can be ascribed to their accessibility and cost, which allow smallholder farmers to use them. On the other hand, because of their greater costs and technological complexity, IoT sensors and drones are less widely used. Adoption rates may increase if these obstacles are removed through training initiatives, incentives, and better rural internet connectivity.

4.2.3 Impact of ICT on Agricultural Productivity

The following findings were found when evaluating the effect of ICT on agricultural productivity: (i) Regression Analysis: the model ($\text{Yield} = \beta_0 + \beta_1(\text{ICT Adoption}) + \beta_2(\text{Farm Size}) + \beta_3(\text{Irrigation}) + \epsilon$) indicates that ICT adoption, in conjunction with variables like farm size and irrigation, positively effects farm yield. (ii) Pre-Post Adoption Data: ICT implementation resulted in a 23% decrease in water use (from 5,200 L/Ha to 4,000 L/Ha, $p = 0.01$) and a 20% increase in yield (from 1,750 kg/Ha to 2,100 kg/Ha, $p = 0.003$).

The study's regression results supported the idea that ICT tools increase production, most likely by facilitating better decision-making (e.g., precision agriculture). The notable decrease in water consumption illustrates how ICT can support sustainable behaviors, which are in line with international objectives for resource efficiency and climate resilience.

4.3 Cost-Benefit Analysis (CBR)

To determine the benefits of using ICT technologies for increased agricultural productivity, a cost-benefit analysis was also conducted and it showed that:

- (i) Mobile apps had the greatest CBR (6.4), demonstrating strong profitability because of their cheap costs (N45) and significant revenue growth (N290), it was demonstrated.
- (ii) Drones were not cost-effective (CBR = 0.6) because of their high

yearly costs (N1,100) and meager income gains (N700), but IoT sensors had a moderate CBR (2.2).

According to this analysis, smartphone apps are the most profitable ICT tool, which makes them perfect for smallholder farmers to use widely. Despite its innovation, drones might not be practical until costs are reduced or alternate funding schemes (like shared ownership) are implemented. To get the most impact, developers and policymakers should give priority to scalable, affordable solutions so that the gains will be felt.

4.4 Implications for Agricultural Sustainability and Food Security

The report has a lot to say about food security and sustainable agriculture. As a result, the following needs to be observed and considered:

- (i) **Education and Training:** Farmers who have received more education are more likely to use ICT tools. Programs for agricultural extension must incorporate digital literacy.
- (ii) **Affordability:** The most accessible tool is a mobile app. While maintaining low costs, efforts should be directed toward increasing their functions (such as market prices and weather predictions).
- (iii) **Sustainability:** ICT technologies contribute to long-term agricultural sustainability by increasing yields while simultaneously conserving resources (such as water).
- (iv) **Policy Support:** To guarantee fair access, governments and non-

governmental organizations should fund rural internet infrastructure and provide subsidies for expensive technologies like drones.

4.3 Important Lessons for Food Security and Agricultural Sustainability

- (i) Although ICT technologies are revolutionary, their deployment must be tailored to the needs of individual farmers.
- (ii) Policy measures (such as training and subsidies) are necessary due to the persistence of awareness gaps, particularly among smallholders.
- (iii) There is strong but geographically skewed evidence of impact; filling key infrastructural gaps (such as internet access) is necessary for scaling up.
- (iv) User demands must be taken into account when developing promotional techniques (e.g., offline functionality for rural places).

The study shows how ICT tools, especially mobile apps, can revolutionize agricultural sustainability and efficiency. However, their effectiveness depends on removing obstacles like infrastructure, education, and cost. Stakeholders can create focused interventions to improve food security and advance sustainable agricultural methods worldwide by utilizing these information.

5.0 Summary, Conclusion and Recommendations

5.1 Summary

This study looked at how ICT technologies can improve food security and agricultural sustainability by examining their uptake,

effects, and marketing tactics. Important conclusions include:

- (i) ICT tools (such as blockchain, IoT sensors, mobile apps, drones, and AI chatbots) improve market transparency, productivity, and resource efficiency.
- (ii) There are notable differences in awareness and adoption: smallholders (2.1/5) lag behind commercial farms (4.5/5) because of infrastructure, expense, and literacy issues.
- (iii) Measurable effects include increased food security (e.g., lower post-harvest losses, water savings) and productivity increases (18–30%).
- (iv) Tailored strategies like farmer field schools, subsidies, and locally relevant material are necessary for effective promotion.

5.2 Conclusion

The study emphasizes how information and communication technologies (ICTs) may revolutionize food security and agricultural sustainability, especially in areas with limited resources. The results of this study are consistent with international data from the World Bank and the Food and Agriculture Organization (FAO), which emphasize the importance of digital technologies in promoting resilience, productivity, and fair growth in agri-food systems (FAO, 2022; World Bank, 2023). The FAO's claim that precision agriculture can maximize resource efficiency is supported by Table 5, which shows that mobile apps and IoT sensors, most

significantly, demonstrated a 20% increase in crop yields and a 23% reduction in water use in achieving increased productivity and sustainability based on ICT adoption (FAO, 2021). Given that just 15.4% of farmers with tertiary education embraced sophisticated technologies, the survey confirms once more that digital literacy gaps continue to be a barrier to digital inclusion and capacity growth (Table 1). This is consistent with research from the International Telecommunication Union (ITU) showing that there are still digital gaps in rural areas ([Mitchell, 2023](#)).

5.3 Recommendations

(a) Interventions in Policy

- (i) ICT tools for smallholders, such as inexpensive IoT kits and drone rentals, should be subsidized by governments and non-governmental organizations.
- (ii) To close connectivity gaps, increase rural internet infrastructure.

(b) Design with the Farmer in Mind

- (i) Create offline features and low-literacy-friendly tools (voice-based applications, visual interfaces).
- (ii) Include instruction in ICT in agricultural extension initiatives.

(c) PPPs, or public-private partnerships

- (i) Work with IT companies to test scalable models (like blockchain for equitable pricing).
- (ii) Use celebrity endorsements to increase outreach and involve young people.

(d) Monitoring and Evaluation

- (i) To evaluate long-term effects, set measures (such as adoption rates and yield variations).
- (ii) To increase confidence in technology, share success stories (such as FAO case studies).

5.4 Areas for Further Research

Further research can be done to enhance this concept with a focus in the following dimensions:

- (i) Geographic Gaps: Research the effects of ICT in underrepresented areas, such as conflict zones and Nigeria at large.
- (ii) Socioeconomic Equity: Examine how farmers' access to and use of ICT varies by gender.
- (iii) New Technologies: Examine AI-powered predictive analytics for climate change adaptation while evaluating how 5G will facilitate real-time Internet of Things sensor networks.
- (iv) Longitudinal Studies: Monitor long-term increases in production and results related to food security over a period of five to ten years.
- (v) Behavioral Barriers: Examine the psychological elements that influence adoption, such as peer pressure and technophobia.

Final Thought

ICT is essential to modernizing agriculture, but it cannot reach its full potential without fair access, user-centered innovation, and strong legislative backing. In order to guarantee that digital innovations benefit all farmers, not just the most connected, future

research should place a high priority on scalability, inclusivity, and interdisciplinary collaboration.

Reference

- Aker, J. C. (2011). Dial "A" for agriculture: A review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, 42(6), 631-647.
- Aker, J. C., & Mbiti, I. M. (2010). Mobile phones and economic development in Africa. *Journal of Economic Perspectives*, 24(3), 207-232.
- Ani, D.P., Chidebelu, S.A.N.D. & Enete, A. A. (2016). Analysis of velocity in Soya beans marketing in Benue and Enugu States, Nigeria. *J Agric Econ Ext & Sci*. 2(1): 155 – 166.
- Biam, C.K & Tarvershima, T. (2020). Food security status of rural farming households in Benue state, Nigeria. *Afr. J. Food Agric. Nutr. Dev.* 20(2), 15677-15694. DOI: 10.18697/ajfand.90.17980.
- Brewster, C., Roussaki, I., Kalatzis, N., Doolin, K., & Ellis, K. (2017). IoT in agriculture: Designing a Europe-wide large-scale pilot. *IEEE Communications Magazine*, 55(9), 26-33.
- Bukhari, S.A.R. (2021). Sample size determination using Krejcie and Morgan table. DOI: 10.13140/RG.2.2.11445.19687.

- Duncombe, R. A. (2012). *Mobile Phones for Agricultural and Rural Development in Developing Countries: A Literature Review and Future Research Priorities*. (Development Informatic Working Paper; No. 50).
- FAO (2018). *The State of Food Security and Nutrition in the World 2018*. Food and Agriculture Organization of the United Nations.
- FAO (2020). *Transforming Food and Agriculture to Achieve the SDGs*. Food and Agriculture Organization of the United Nations.
- FAO. (2021). In Brief to The State of Food and Agriculture 2021. Making agrifood systems more resilient to shocks and stresses. Rome, FAO. <https://doi.org/10.4060/cb7351en>.
- Ferris, S., Engoru, P., & Kaganzi, E. (2014). Making market information services work better for the poor in Uganda. *African Journal of Agricultural and Resource Economics*, 9(3), 1-13.
- Gebbers, R., & Adamchuk, V. I. (2010). Precision agriculture and food security. *Science*, 327(5967), 828-831.
- Jumanne, A. S. (2024). Leveraging digital technologies for sustainable agriculture in enhancing social and economic development in Kenya. *International Journal of Agriculture*, 9(2), 13-23.
- Kamilaris, A., & Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. *Computers and Electronics in Agriculture*, 147, 70-90.
- [Mitchell, M.](#) (2023). Reducing the Digital Divide in Rural Africa. Available at: <https://www.byarcadia.org/post/connecting-the-unc>.
- Mittal, S. & Mehar, M. (2013). Agricultural information networks, information needs and risk management strategies: a survey of farmers in Indo-Gangetic plains of India. Socioeconomics Working Paper 10. Mexico, D.F.: CIMMYT
- Pretty, J. (2008). Agricultural sustainability: Concepts, principles, and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 363(1491), 447-465.
- Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID and blockchain technology. *IEEE 13th International Conference on Service Systems and Service Management (ICSSSM)*, 1-6.
- United Nations (2015). *Transforming our World: The 2030 Agenda for Sustainable Development*. United Nations.
- World Bank (2019). *Harvesting Prosperity: Technology and Productivity Growth in Agriculture*. The World Bank.

World Bank. (2023). Digital Climate Information and Agriculture Advisory Delivery Mechanisms in

West Africa.
[https://documents1.worldbank.org
> curated > pdf.](https://documents1.worldbank.org/curated/pdf)