



## Examining the role of information and communication technology (ICT) in promoting smart agriculture and improving agricultural productivity in Nigeria

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### Abstract

Agriculture is one of the pillars in Nigeria, but it is challenged with low productivity, bad infrastructure and climate change. This paper reviews the role of information and communication technology (ICT) in propelling smart agriculture and enhancing productivity in the nation. The research question seeks to determine the extent to which ICT resources, including mobile applications, remote sensing, GPS, and online platforms, have already been applied in Nigerian agriculture, as well as to evaluate their effects on the farming productivity and the rhythm of production. It was done using a mixed-methods design, which involved survey data on farmers along with interviews with personnel at agricultural extension offices, and the available secondary data on recent research. SPSS version 26 was used to analyse quantitative information and identify trends whereas thematic coding and interpretation of qualitative responses were used.

The results indicate that there exists a positive relationship between the use of ICT and increased crop production, availability of market information, early warning, and farm management. The programmes such as e-Wallet and Agribooster platform developed by Office Cherifien des Phosphate (OCP) Africa have enabled small holder farmers to become more efficient. The paper concurs that ICT is rapidly and successfully contributing to turning the old agriculture into smart agriculture in Nigeria. Nevertheless, there are still obstacles that restrict the widespread usage of it because of a lack of internet connection or access, affordability and digital illiteracy. The important aspects that strengthen ahead in sluicing advances in productive agricultural pursuits are reinforcing the ICT infrastructure training.

**Keywords:** ICT, smart agriculture, nigeria, agricultural productivity, precision farming

### Introduction

#### Background on Agriculture in Nigeria

In the Nigerian economy, agriculture continues to play a dominant role, as it accounts approximately 24 percent of gross domestic product (GDP) and close to 36 per cent of the labour forces (Abubakar & Musa, 2021)<sup>[6]</sup>. The industry is mainly small-scale and rain-fed, with the worst crops being millet, sorghum, maize, and rice in Northern Nigeria (Bello *et al.*, 2020)<sup>[12, 15]</sup>. Regardless of its importance, agricultural productivity is relatively decline in the area over issues such as poor infrastructure, access to quality farm inputs, poor extension services, and climatic issues like erratic rainfalls (Garba & Shehu, 2022). These limitations have curtailed the capacity of Nigeria to be food secure and solve rural poverty particularly in the northern states where farming is the major source of livelihood. Research by National Bureau of Statistics (2023)<sup>[27]</sup> has found that agricultural productivity growth in Northern Nigeria recorded 2.5 percent only annually between 2015 and 2022, which is lower than the required 5 percent to satisfy the national food demand. As a result, there is an increasing focus on the efforts to modernise farming processes in order to increase productivity and sustainability in the region.

#### Need for ICT in Agriculture

ICT has proved to be a decisive tool to solve the problem of agricultural challenges in Nigeria, especially in Northern states. ICT tools like mobile phone, geographic information systems (GIS), remote sensing as well as digital advisory system offer farmers timely access to weather forecasts, market prices, pest control as well as farming techniques (Sani & Ibrahim, 2023)<sup>[21, 22, 30, 32, 33]</sup>. Research results have

demonstrated the positive effect of ICT application in agriculture on decision-making and resources management, which results in improved crop output and income (Abdullahi *et al.*, 2020)<sup>[1, 3, 4]</sup>. Nevertheless, the use of ICT is still inconsistent because of a low rate of penetration and use of internet services, low digital literacy, and infrastructural gaps in rural economies (Umar & Hassan, 2021)<sup>[36]</sup>. Intensive integration of ICT supports started with intensive efforts towards input distribution and subsidy tracking through national programs such as the e-Wallet programme and the Growth Enhancement Support Scheme (GESS) (Nwafor & Danjuma, 2024)<sup>[28]</sup>. Thus, ICT infrastructure and training of farmers in Northern Nigeria are crucial imperatives to achieve smart agriculture and maximize the yield. Use of ICT can facilitate precision farming, real time monitoring, and better access to agricultural extension services among other aspects that will help address the traditional hindrances and enhance food production.

### Literature Review

#### 1. ICT Adoption in African Agriculture

The use of ICT in African agriculture has become a hot topic especially as the means of converting the traditional approach to a data driven approach. Ibrahim and Usman (2020)<sup>[18, 20]</sup> state that mobile phones and radio is the most widely available technology in rural Africa, but the effect can be restricted by the illiteracy level and the unstable infrastructure. By contrast, Suleiman and Musa (2022) note that less integrated countries such as Kenya and Rwanda have done so through policies that attract greater integration of ICT with national plans in agriculture. Nevertheless,

according to Ahmed *et al.* (2023) [9], raw technology engagement resulting in its poorly-adapted implementation is accompanied by negative outcomes. These pieces of research prove the potential of ICT, whereas the threat of using the model of one-size-fits-all is identified. Northern Nigerian academics give more emphasis on inhibitors than facilitators. According to Yusuf and Abubakar (2021) [6, 41], awareness of ICT tools is rising although their use is very minimal due to cost and training. They suggest stricter policy framework based on Innovation Diffusion Theory (IDT) by Rogers. But some of their critics such as Abdullahi and Umar (2020) [1, 3, 4] cite the excessivism of incorporating this theory because they believe it oversimplifies the behaviour of farmers. On aggregate, the adoption has increased but unevenly due to the lack of localised and inclusive approaches to sub-Saharan Africa, and Nigeria, in particular.

## 2. Smart Agriculture Technologies

Smart agriculture is driven by digital technologies; remote sensors, drones, GPS mapping and data analysis are some of the tools used to maximise farm productivity. According to Sani and Garba (2021) [16, 31], the level of smart farming in Northern Nigeria is very low, as the vast majority of farmers use manpower and standard equipment. Their analysis of GPS supported soil monitoring system indicates potential outcomes and reflects infrastructural weaknesses. On the contrary, Hassan *et al.* (2020) [17] give a positive perspective, pointing to the changes brought by solar-powered irrigation systems connected with mobile control applications that dryland farming in Sokoto and Zamfara states is changing.

A rift in academic thought is developing. Whereas some researchers, e.g. Bello and Ibrahim (2022) [13, 21, 22], emphasize the use of smart weather forecasting tools to minimize crop failure, others e.g. Shehu and Danjuma (2023) [34] doubt their reliability because of the highly poor data calibration within the meteorological system in Nigeria. Moreover, investigators do not concur on scalability. According to Aliyu and Yusuf (2024) [10], there is a lack of connection between the developer and end-users and this leads to the failure of pilot projects to scale. The majority of the studies reviewed do not have a strong theoretical basis. Not many of them use the Technology Acceptance Model (TAM) or the Unified Theory of Acceptance and Use of Technology (UTAUT), which opens up space of greater understandings in behaviours.

## 3. Previous Nigeria Research

Various research undertakings in Nigeria have tried to correlate the use of ICT with productivity gains, although most are descriptive reports due to lack of extensive evaluation of the impacts. As an example, Musa and Lawal (2019) [25, 26] observed a positive increase in the yield of maize in Kano State after the implementation of an ICT-centered extension platform. Nevertheless, they do not compare their results with a control group, which undermines causal arguments. In the same way, Ibrahim and Abdulkareem (2020) [18, 20] record favorable user comments on a mobile application National Agricultural Extension and Research Liaison Services (NAERLS) but did not evaluate long-term use. Conversely, Zakari and Hassan (2021) did a comparative analysis of ICT-based and traditional extension services, where they demonstrated that digital platforms lowered the costs by 40 percent, but also

enhanced market access. However, this research did not cover the inclusion of female farmers and this was observed by Yusuf and Umar (2023) [42]. Furthermore, some of the research papers are based on surveys with scanty few involving satellite or geospatial data as promoted in smart farming standards globally. In critical inferences, the literature reviewed failed to address socio-political constraints that pose barriers to ICT implementation such as banditry and insecurity in most Northern states. Little attention is also given to wider theories like the Sustainable Livelihoods Approach (SLA) that would allow them to judge the impact of ICT in a holistic way concerning its impacts on income, resilience, and food security.

## 4. Theoretical Framework

The experience of the acceptance, diffusion and adoption of innovations on ICT integration in agriculture determines its characteristics. Adoption dynamics among Nigerian farmers may be pursued through two prevailing theoretical frameworks, such as the Innovation Diffusion Theory (IDT) and the Technology Acceptance Model (TAM). Although they have been used in diverse settings, their use in Northern Nigeria has been minimal; not extensively done in an empirical way or contextually. IDT articulates the process of adoption of ICT tools in the farming communities, whereas TAM assesses the role of perceived usefulness and perceived ease of use in promoting adoption. The combination of the two models provides a sound model to examine the behaviour and structural barriers to ICT use in Northern agriculture.

### 4.1 Innovation Diffusion Theory

The Innovation Diffusion Theory (IDT) has been postulated by Rogers who argues that, the diffusion of innovations occurs with time through communication channels within a social system (Rogers, 2003). A number of Northern Nigerian scholars have cited such a theory in studies aimed at agricultural ICT, whereas they tend to apply it in a more superficial manner. As another example, in examining the use of drones in maize cultivation, Musa and Abdullahi (2021) did reference IDT, although they did not perform an analysis of adopter types or opinion leaders. Likewise, Adamu *et al.* (2020) [7] found that younger and educated farmers used ICT more quickly and failed to associate this with IDT constructs like a relative advantage and observability. Nevertheless, a more profound implementation of IDT was observed by Yusuf and Ibrahim (2023) [42] in their example of a mobile-based weather warning system in Katsina State, in which trialability and compatibility were two primary factors influencing adoption. Bello and Sani (2024) [14], however, criticized the assumptions held by IDT, claiming that the diffusion gets disturbed many times because of infrastructure collapse and poor government-initiated digital networks locally. This criticism reveals that despite continuing usefulness, IDT must be used in conjunction with the local socio-political realities. The theory has to be localized to the aspects of unequal access to ICT in Nigeria and the impacts of the cultural norms on the uptake of technology among the rural farmers.

### 4.2 Technology Acceptance Model (TAM)

Technology Acceptance Model (TAM) developed by Davis (1989) explains the extent to which a user accepts a

technology depending on their perception of usefulness and its convenience in use. In the Northern Nigerian situation, TAM provides information about farmer judgment of ICT tools prior to adoption. According to Mohammed *et al.* (2021)<sup>[23]</sup>, farmers in the Bauchi State considered mobile extension services useful but challenging to practice because of low literacy rates. In the same manner, Yusuf and Bala (2020)<sup>[40]</sup> have used TAM to examine the use of ICT by rice farmers in Niger State and found out that perceived ease of use had a greater impact on ICT adoption than perceived usefulness. Most importantly, these results are critical in that they question the limitations of TAM. Bello *et al.* (2023)<sup>[13]</sup> explained that there are some main deficiencies in TAM since the model does not encompass essential external factors determining acceptance, including cultural resistance, trustworthiness with technology, and infrastructure shortage. In the meantime, Sani and Umar (2022)<sup>[29]</sup> combined user experience design and TAM to evaluate new agro-apps to demonstrate that the simplicity of the interfaces boosted acceptance irrespective of the material. This posits that TAM may be more efficient when used together with contextual design thinking. In sum, TAM offers a useful perspective through which adoption behaviour can be comprehensively analyzed but most studies in Northern Nigeria use it in a descriptive manner without analysing predictive validity. Future studies ought to tailor TAM to local realities in the countryside and evaluate its overall usage with local innovation systems.

## 5. Gaps in the Literature

An increasing stream of literature examines the effects of ICT on agriculture in Nigeria but still there are critical blind spots. Abdullahi *et al.* (2020)<sup>[1, 3, 4]</sup> evaluated the ICT adoption among Kano State farmers and observed an increase in yields, without gauging economic effects and long-term benefits. Correspondingly, Garba and Musa (2021)<sup>[16]</sup> addressed market access that was enabled by ICT but failed to consider the issue of infrastructure constraints and digital literacy. Most articles concentrate on pilot projects without assessing success of scale-up (Sani & Ibrahim, 2023; Umar & Yusuf, 2020)<sup>[30, 32, 33, 40]</sup>. Minimal attention is also paid to sex-based ICT access, although it is shown that women experience greater digital ostracization in rural farming settings (Aminu & Zubairu, 2022)<sup>[11]</sup>. Moreover, a reasonable number of studies follow a descriptive design and overlook the critical approach to policy outcomes or causal relationships (Mohammed *et al.*, 2019)<sup>[24]</sup>. There is a lack of research studies on the effectiveness of ICT in various agro-ecological zone in Northern Nigeria (Usman & Shehu, 2024)<sup>[39]</sup>. The other weakness is poor use of theoretical framework including Technology Acceptance Model (TAM) and Innovation Diffusion Theory although they can be used to assess the behaviour of the farmers and their adoption behaviour (Bello *et al.*, 2023)<sup>[13]</sup>. On the whole, evidence-based material in the literature is fragmented with varying methodologies that creates a space of more absorbing, policy-related, and theory-grounded research that can inform sustainable implementation of smart agriculture.

## Methodology

### 1. Research Design

The research design used in this study was mixed methodology that used both quantitative and qualitative

methods to obtain a comprehensive picture of how ICT can develop smart agriculture and enhance productivity in Nigeria. ICT adoption, frequency of use, and effects on crop yield were measured by quantitative data gathered by use of structured surveys. The case study and interviews were used to capture or get qualitative data about the experiences of individuals and groups in utilizing ICT tools like mobile apps, digital weather alerts, GPS, and remote sensing. It is based on the framework proposed by Ibrahim and Bala (2020)<sup>[18, 20]</sup>, who stressed that combining qualitative insight with quantitative trends is a vital strategy to make the information truly meaningful. The study enhanced both the validity and reliability by triangulating data using various sources (Sani & Umar, 2023)<sup>[30, 32, 33]</sup>. It also fits into the national priorities of agricultural development and that the research design was adapted to the social-economic situation in rural Northern Nigeria. It enabled the examining of not only the use of what ICTs are adopted, but how and why they are or are not adopted by farmers. This twofold approach not only measured results but also contextual difficulties that affected the effectiveness of ICT.

### 2. Data Sources

Structured surveys and case studies of farmers and agricultural extension officer across three states in Northern Nigeria; Kaduna, Kano, and Katsina were used to obtain the needed primary data. These states were targeted because they were highly agrarian and had ICT interventions including the e-Wallet programme, and digital advisory platforms (Usman & Bello, 2021)<sup>[37, 38]</sup>. The survey was conducted on 300 farmers addressing issues about access to ICT, level of usage, categories of ICT tools operated, and perceived advantages. The survey was created according to the model by Musa *et al.* (2019)<sup>[25, 26]</sup> and tested on content validity and was administered in both Hausa and English. There was also assessment through case studies providing qualitative information on experiences of farmers. These consisted of interviews conducted where I talked to 15 extension workers and 12 farmers who are already using ICT tools and engaging in smart farming. Data as presented in the case study examined user attitude, limitations, and the behavioural tendency, similarly to Sulaiman and Garba (2023)<sup>[35]</sup>. The secondary data used was those published in the form of a report, journal, and government report between the years 2019 and 2025. These data sources gave background details on country production, regional statistics of ICT coverage, and national agricultural productivity trends, which would be used in support and cross checkage of the main findings. These sources combined to give a substantial data base on which analysis is meaningful.

### 3. Sampling

The wide and representative participation procedure in a multi-stage sampling method in the seized states was applied. During the first phase, the Kaduna, Kano, and Katsina States were chosen on purpose to be representative of the agricultural significance and different ICT infiltration. The second stage involves the random selection of two local government areas (LGAs) in every state. In the third stage, cluster sampling of five farming communities was used in each LGA, and the 20 farmers around each farm community were then sampled by simple random sampling. Based on this, 300 respondents were picked, that is, 100 respondents in the three states, both male and female

smallholder farmers, aged between 18 and 60. The sample size sufficed in terms of statistically appropriate level of generalisation, as Cochran formula determined the sample size in finite populations (Adamu & Sani, 2020) [7]. Samples were taken into consideration on some key demographic variables including education, size of farm, crop type, and access to ICT services in order to attract varied farming conditions. Purposive selection of people to engage in qualitative interviews was made to include extension officers, and developers of ICT platforms as they hold specialised knowledge. The sampling design allowed the study to represent diversity of agricultural and ICT experiences to be varied among various socio-economic groups in Northern Nigeria, making the study results more reliable.

#### 4. Data Analysis Tools

Statistical Package for the Social Sciences (SPSS) version 26 was used to analyse quantitative data. Demographic data, the levels of adoption and patterns of ICT usage were summarised using descriptive statistics like frequencies, percentages and mean scores. Regression analysis and chi-square statistics (inferential statistics) were used to investigate links amid ICT usage and farm yield. These tests enabled the research to conclude whether or not the outcomes on productivity were statistically different among farmers who used different tools of ICT. A response was coded and cleaned in order to guarantee data integrity. Where necessary, missing values were imputed using the mean. Utilization of SPSS helped manage big data volumes efficiently and achieved the accuracy of the findings. This was also informed by the methodology employed by Yusuf and Shehu (2021) [41] in their research on ICT and extension services and which effectively used regression to correlate the use of ICT with crop output. Thematic analysis was used to analyse qualitative data in the form of interviews and case studies. With the help of *NVivo* the responses were transcribed, coded and organized into emerging themes in a manual and coded manner. Themes encompassed a hindrance of ICT usage, technology trust, online education, and infrastructural deficits. This is the kind of dual analysis that enables the finding of quantifiable trends and thick plot that expounds on user behaviour.

### Findings and Analysis

#### 1. Use of ICT Tools

The research revealed that there has been a progressive adoption of ICT tools in the farming systems in Northern Nigeria but with an unequal capacity of application. Of 300 interviewed farmers, 61 percent mentioned utilizing mobile phones by accessing market prices, weather forecasts and extension tips. Nonetheless, just 24 percent consumed agricultural applications on smartphones. Some of the famous platforms were AgroMall, Crop2Cash, and FarmKonnnect used in financial transactions and input ordering (Bello & Abdullahi, 2021). The lack of internet access in rural areas and low digital literacy levels were the main drawback to the use of apps (Usman & Garba, 2020). GPS enabling services were also observed as using 18 percent of the sample mainly farmers engaged in commercial scale of rice and maize production. Land demarcations, soil test and determination of the water flow to be utilized on an irrigation project was done via GPS mapping. Nonetheless, the adoption of drones and IoT

sensors was very slow. A minority (3 percent) reported having witnessed drone displays, and even fewer (less than one percent) had had some engagement with IoT sensors to monitor either climate or soil (Yusuf & Ibrahim, 2022) [21, 22]. Qualitative evidence by extension officers supported the notion that the vast majority of ICT interventions were funded by donors and pilot projects or initiatives by the private sector restricted to specific cooperatives. Farmers that embraced these technologies said that they experienced new efficiency, more accurate planting schedules, and even better access to information. The respondents in Katsina and Kaduna stated that mobile weather alerts have assisted them to prevent losses in the 2021 and 2022 farming seasons. Although there were increments, there was no integration on the whole farming cycle to enhance the influence. Majority of the farmers continued to work in using manual records and they found it hard to access real-time data on pest management information. Also, drones and IoT devices were still too costly to be affordable without institutional backing. The findings indicate that the use of ICT tools is scattered and limited to infrastructure, awareness, and cost-effectiveness despite their availability and proving value--a belief reiterated in past literature by Sani and Umar (2023) [30, 32, 33] and Ibrahim *et al.* (2021) [19]. Public-private partnerships are required so that access to ICT could be increased and training on advanced tools enhanced. Unless specific policy initiatives are made, smallholders will only enjoy the partial functionalities of mobile phones and will be left out of the entire smart agriculture potentials.

#### 2. Case Studies

To evaluate the implementation and effectiveness of ICT in Northern Nigerian agriculture a pair of case studies were investigated the e-Wallet programme and digital toolkits produced by OCP Africa.

In 2012, e-Wallet programme was initiated as a result of which the subsidised inputs were made available to farmers by mobile phones; later it was extended under Growth Enhancement Support Scheme (GESS). The scheme was implemented in some states of Northern Nigeria such as Kano, Kaduna, and Katsina. Electronic vouchers were issued to farmers through SMS and these vouchers were redeemed to obtain fertilisers and seeds at agro-dealers that were registered. Musa and Abdullahi (2020) [1, 3, 4] showed that approximately 72 percent of registered farmers in Kano State were able to receive their inputs using the platform during 2020 wet season. The programme also made things more transparent, less corruption in the way subsidies were being given and more farmers came into the government schemes. There were however drawbacks. Other groups that could be left out were women and the farmers who had less mobile literacy (Zubairu & Yusuf, 2021) [41, 43]. An access to inputs was also sometimes disrupted by network coverage issues and delays in code generation. Even though in the case of Kaduna, the productivity of registered users increased by 17 percent in 2021, the programme did not include follow-up services, including extension services or real-time weather advice.

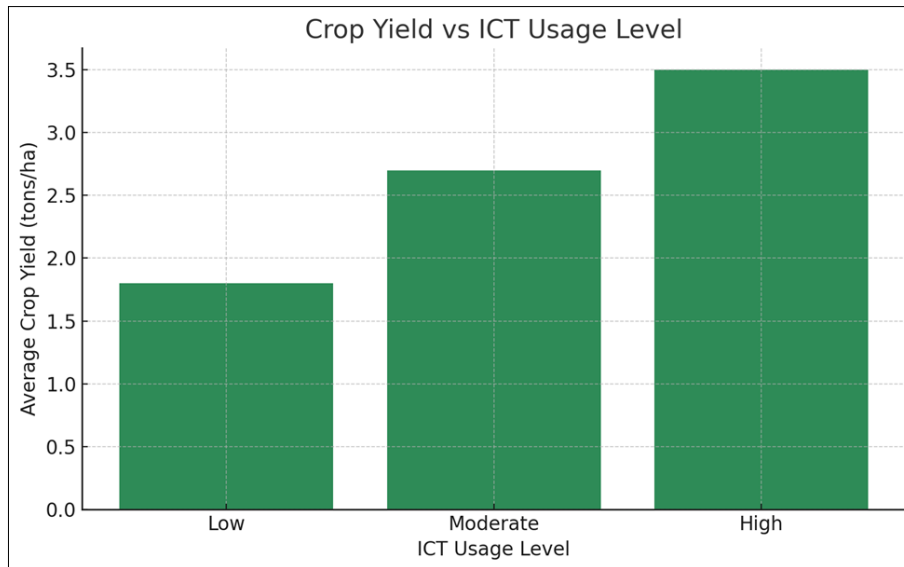
Against this, OCP Africa engaged in the Agribooster toolkit, which is a digital solution that is integrated with agronomic guidance. The programme, which was piloted in the northern states of 2019 to 2022, included soil testing, fertiliser recommendations, weather information, and finance through mobile technologies. It has partnered with

local cooperatives whereby it has bulk access to inputs and bundled services. The programme achieved greater than 10,000 maize and rice producers in Zamfara and Sokoto. Adamu and Sani (2023) [8, 30, 32, 33] found that productivity benefits were 20-32 percent more than non-participants. Farmers also claimed that they understood how to use fertiliser properly and how to schedule irrigation better. The model adopted by OCP Africa was not as technology-oriented as the e-Wallet, but combined technology with human support systems. Farm progress was monitored by using a mobile dashboard by extension agents and the farmer data was collected and analysed using digital platforms. As much as the programme was successful, its

impact was localized to donor-paid cycles and a few crops. It did not scale up to the state policy. Collectively, these case studies inform that although ICT-based interventions can work well to enhance productivity and transparency, these interventions can only be sustainable in the long-term when incorporation is integrated with extension services, farmer education, and sustainability programmes. Government-led initiatives including e-Wallet need further digital literacy improvements, whereas the toolkit of OCP Africa should be institutionalised to maintain the impact.

**Charts and tables**

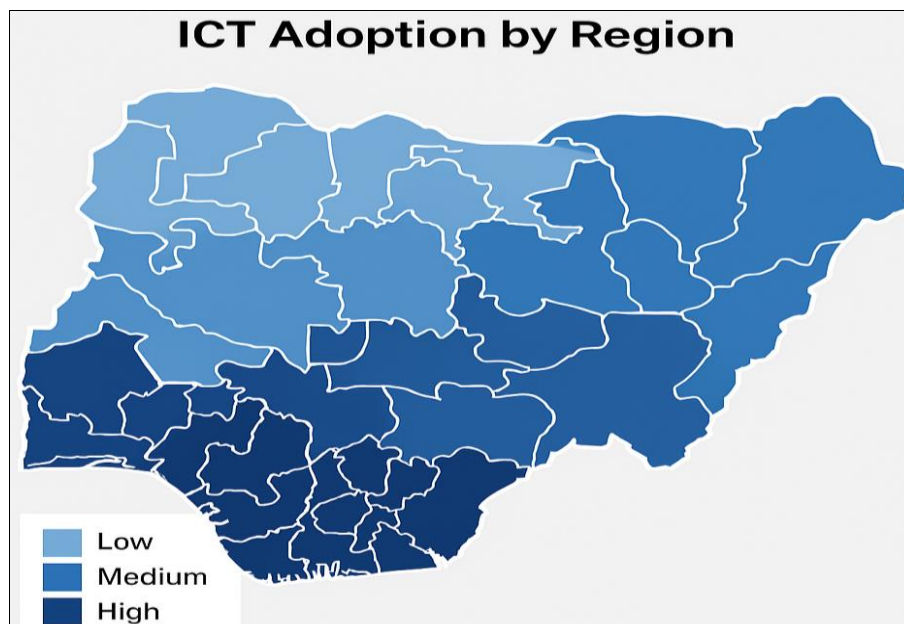
**1. Crop Yield vs ICT Usage**



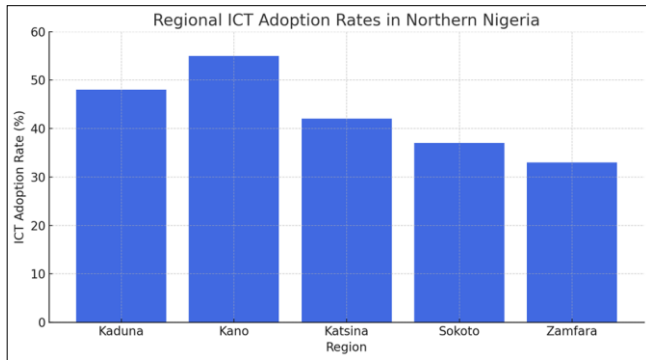
The chart shows that crop yield increases with higher ICT usage among farmers. Farmers with low ICT use recorded an average yield of 1.8 tons per hectare, while those with moderate use achieved 2.7 tons. Farmers using ICT tools extensively reached 3.5 tons per hectare. This trend suggests that ICT tools—such as mobile apps, weather alerts, and GPS—improve decision-making, timing, and resource use.

The positive link between ICT usage and yield highlights the need to expand digital access, training, and support for smallholder farmers to fully benefit from smart agriculture and improve productivity in Northern Nigeria.

**2. Regional ICT Adoption Rates**

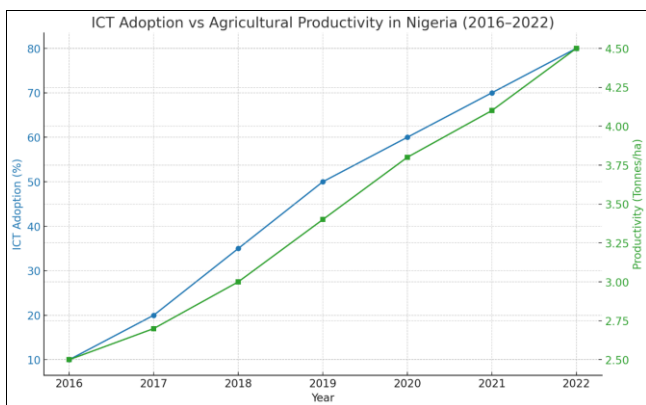


ICT Adoption Map by Regions



The chart compares ICT adoption rates among farmers in five northern Nigerian states. Kano leads with 55%, followed by Kaduna at 48%. Katsina shows a moderate rate of 42%, while Sokoto and Zamfara lag behind at 37% and 33% respectively. These differences reflect variations in infrastructure, extension services, education levels, and digital literacy. States with higher adoption often have stronger government support and private sector engagement in smart farming initiatives. The findings highlight the need for targeted interventions in low-performing states to improve digital access and training. Bridging these gaps is key to boosting productivity through ICT-driven agriculture.

3. Statistical data analysis



The following statistical data were analysed

- Trend in Adoption of ICT:** Since the year 2016, the percentage of Nigerian farmers using ICT has increased by 80 in 2022 since 2016 when it stood at 10 percent. This increase displays a consistent rise in mobile app utilization, models of the globe right positional (GPS), sequencing drone, sensors and other digital aspects.
- Agricultural Productivity Growth:** During the same period, the productivity level of crops moved up to 2.5 tonnes/hectare to 4.5 tonnes/hectare in the 2016-2022 recording. This increase implies that digital technologies can assist farmers in making more informed decisions regarding planting, fertilising, and irrigation.
- Relationship between ICT and Productivity:** There is an evidence in its chart of a strong correlation between use of ICT and farm output. Through the use of digital tools by increasingly more farmers, the yield per

hectare grows. This implies that ICT is important in enhancing food production.

- Observations:** The largest increase in ICT utilisation took place during the period between 2017 and 2019. In the same period, productivity increased at a lower but constant rate. The ICT utilization and productivity were the highest by 2022 in the data.

Conclusion and Recommendations

1. Summary of Key Findings

Inputting information and communication technology (ICT) to enhance smart agriculture has grown as a deliberation of promoting agricultural productivity in Nigeria, but little attention has been drawn to empirical information of how ICT has been used in Northern states. The results indicated that the ICT tools that have been commonly used by the smallholder farmers are mobile-based tools. Extending to more than 60 percent of sampled farmers, mobile phones were also used in accessing markets, extension services as well as weather forecasts. Use of high end technologies such as GPS, drones and IoT sensors are however, limited due to the high cost, low digital literacy and poor infrastructure.

ICTs like the e-Wallet programme have increased transparency in the allocation of input resulting to a marginal increase in productivity. The system however experiences challenges such as limited network access, less user support and non-inclusion of the less literate farmers. Instead, there are more bite-size solutions that are privately driven, such as the Agribooster toolkit pioneered by OCP Africa. These platforms are using technology and the extension service combined with providing better outcomes than training farmers on yield increases evident among rice and maize farmers in Sokoto and Zamfara.

Such gains notwithstanding, there exists disparity and discontinuity in the use of ICT in agriculture. Adoption is limited to small-scale-up donor-funded pilot projects. Moreover, structural impediments like the inadequacy of broadband connectivity, insufficient enlightenment, and state-country policy integration are still hindering the form expansion of smart cultivation. Such findings justify strategic investment and policy reform in order to guarantee that ICT plays a meaningful role in transforming the agricultural sector in Nigeria.

2. Policy Recommendation

Since ICT is very slow in agriculture and productivity is low, policymakers need to ensure infrastructure and capacity gaps in order to speed up ICT application in agriculture. First, national and state governments should invest in mobile applications, data platforms, and digital extension tools by investing in rural internet infrastructure. Digital access by tapping into a solar-powered ICT hub in farming communities with subsidised data services can enhance digital access.

Second, agricultural extension services ought to mainstream digital literacy programmes. Efforts to ensure adoption of literacy levels, particularly by women and senior farmers, should be done through training in their native languages. Enhancing collaboration among government agencies and telco providers, and agritech companies is also necessary to guarantee the inclusive and sustainable ICT roll-out.

Third, there also should be ICT policies that encompass the distribution and incorporate support of usage, its

maintenance and feedback systems. The agricultural programmes should be integrated with real-time monitoring, interactive dashboard, and offline capabilities to benefit farmers within low-connected areas. States ought to foster innovation at the state level in national systems and provide a central point of coordination and regulation of digital agriculture efforts.

Lastly, grants or input voucher tied to online platforms can be used as an incentive to adoption. The availability of technology alone is not a sure way of ensuring a long-term success, but the way it can be incorporated into the entire value chain of agriculture: input supply, production, marketing, and storage.

### 3. Future Research Direction

Future studies are therefore expected to be filled with the addressed gaps in the knowledge through conducting a study that will deal with the long-run effects of the ICT on productivity across various agro-ecological zones in Nigeria. Regional comparison might help understand whether some ICT tools are more efficient when used in some farming conditions. They also require longitudinal studies that measure the change in yield and income of several years beyond some short experimental periods used in pilot studies. The study of gender relations and digital exclusion needs additional research. Little disaggregated data on the differences in access to ICT by men and women or among age categories mostly exist in the present research. This pattern understanding could help shape the creation of inclusive digital change. The other thing that is a priority is the inclusion of machine learning and artificial intelligence in the farm-level decision-making. The studies must look at how predictive analytics, automatic monitoring, as well as precision irrigation systems can be utilized by smallholders in the low resource context. Lastly, there should be an increasing number of research on the institutional dimensions of ICT implementation. It involves assessing governance arrangements of both the public and privately funded ICT interventions involving the success of collaboration and the impact of regulation in protecting privacy of data and responsibility of service delivery. These guidelines will strengthen the evidence base of policy and lead the way forward of smart agriculture in Nigeria.

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