Mobile Agricultural Applications as Digital Extension Tools for Enhancing Smallholder Farmers' Productivity in Benue State, Nigeria

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ABSTRACT

The study assessed the use of mobile agricultural applications as digital extension tools for improving smallholder farmers' productivity in Benue State, Nigeria. A mixed-methods approach involving survey research and key informant interviews was adopted. Structured questionnaires were administered to 210 smallholder farmers and 25 extension agents selected from the three agricultural zones of Benue State. Data were analyzed using descriptive statistics, Pearson Product Moment Correlation (PPMC), and logistic regression analysis. Findings revealed that 46% of the farmers regularly used mobile agricultural applications for accessing extension information, while 38% utilized mobile platforms for weather updates and pest management information. About 42% accessed market price information through mobile applications, whereas 51% reported improved farming decisions and adoption of improved agricultural practices through digital extension services. Correlation analysis showed a significant relationship between farmers' education level and mobile application usage ($r = 0.61$, $p < 0.05$). Logistic regression analysis revealed that smartphone ownership ($\beta = 0.49$, $p < 0.01$) and internet access ($\beta = 0.37$, $p < 0.05$) significantly influenced utilization of mobile extension platforms. The study concluded that utilization of mobile agricultural applications among smallholder farmers remains relatively low despite their potential for improving productivity and extension delivery. Increased investment in rural digital infrastructure and farmer digital literacy training was recommended.

Keywords: Mobile Applications, Digital Extension Services, Smart Agriculture, Agricultural Productivity, Smallholder Farmers.

INTRODUCTION

Background to Digital Agriculture

Digital agriculture has emerged as an innovative approach for improving agricultural productivity, enhancing global food security, and promoting sustainable farming systems. The integration of digital technologies such as mobile applications, internet-based advisory platforms, artificial intelligence, and precision farming tools into agricultural production has fundamentally transformed the way agricultural information is generated, disseminated, and utilized (Food and Agriculture Organization [FAO], 2022). In developing countries like Nigeria, digital agriculture is increasingly recognized as a practical, scalable solution to structural challenges associated with low agricultural productivity, information asymmetry, and poor physical access to conventional extension services among smallholder farmers (Aker, 2011).

Mobile agricultural applications have become important tools for facilitating real-time communication between farmers, extension agents, researchers, and market actors. Through these digital platforms, farmers can bypass geographic barriers to obtain critical information on localized weather forecasts, pest and disease management, precise fertilizer application rates, improved seed varieties, and real-time market prices (Mittal and Mehar, 2016). The increasing penetration of mobile telecommunication infrastructure and affordable smartphones in rural communities has further opened up unprecedented channels for decentralized agricultural information dissemination and rapid technology transfer.

Agricultural Extension Challenges in Nigeria

Agricultural extension services play a significant role in transferring agricultural innovations, modern techniques, and agronomic best practices to rural farmers. However, public extension delivery systems in Nigeria continue to face deep institutional challenges that drastically limit their field effectiveness. According to Nwafor et al. (2021), chronic inadequate funding, poor rural transportation facilities, insufficient extension personnel, and weak institutional support have combined to cripple physical extension service delivery across rural communities.

The ratio of extension agents to smallholder farmers in Nigeria remains vastly below international standards, hovering around one agent to several thousand farmers, which minimizes regular face-to-face interactions (Madukwe, 2018). Consequently, millions of rural farmers are left without access to timely, reliable, and scientifically verified agricultural information. Traditional public extension approaches are logistically unable to meet the expanding, fast-changing information demands of modern smallholders, particularly those situated in remote, hard-to-reach communities.

Importance of Mobile Agricultural Applications

To fill these structural communication gaps, mobile agricultural applications are actively being integrated into digital extension systems across developing economies. These applications provide farmers with accelerated, unmediated access to technical information at a fraction of the cost associated with physical travel. Mobile platforms empower farmers by providing continuous updates on micro-climate conditions, volatile market trends, input availability, and pest mitigating protocols (Baumüller, 2018).

The systematic deployment of mobile agricultural applications has been shown to improve farmers' decision-making speeds, increase the adoption rates of certified agricultural technologies, and structurally strengthen the collaborative feedback loop between smallholders and research institutions (Mittal and Mehar, 2016). Furthermore, digital extension environments cultivate peer-to-peer knowledge sharing and minimize the historical information advantage held by urban middle-tier brokers. As a result, mobile applications are increasingly categorized as crucial pillars for driving rural livelihood improvements and climate-smart agricultural compliance.

Problem Statement

Despite the theoretical and clear economic advantages of digital agricultural technologies, the actual field utilization of mobile agricultural applications among smallholder farmers in Nigeria remains stubbornly low. A large proportion of rural farmers continue to rely entirely on traditional, often inaccurate, sources of agricultural information due to deep-seated structural issues. These include poor rural internet connectivity, widespread digital illiteracy, the prohibitive cost of internet-enabled smartphones, and a lack of formal awareness regarding existing digital extension platforms (Aker, 2011).

In Benue State, where agriculture serves as the primary economic engine and foundational source of livelihood, limited access to synchronized agricultural information continues to depress crop yields and aggregate productivity among smallholders. Although various public and private digital agricultural platforms have been launched over the last decade, their specific field utilization rates, operational constraints, and direct impacts on smallholder decision-making remain poorly quantified. There is, therefore, a critical empirical need to assess the extent to which mobile agricultural applications are utilized as digital extension tools and to isolate the socioeconomic factors that govern their adoption within Benue State.

Objectives of the Study

The broad objective of the study was to assess the use of mobile agricultural applications as digital extension tools for improving smallholder farmers' productivity in Benue State, Nigeria.

The specific objectives were to:

1. Determine the level of utilization of mobile agricultural applications among smallholder farmers across distinct information categories.
2. Identify the specific agronomic and economic benefits derived from using digital extension services.
3. Quantify the socioeconomic and infrastructural factors influencing farmers' utilization of mobile agricultural applications.
4. Identify and rank the primary constraints affecting the effective deployment and use of digital extension platforms among rural farmers.

THEORETICAL FRAMEWORK

This study is anchored on the Diffusion of Innovation (DOI) Theory developed by Rogers (2003). The theory explains how new ideas, technologies, and innovations spread through social systems over time. According to the theory, the adoption of an innovation depends largely on how potential users perceive its characteristics, including relative advantage, compatibility, complexity, trialability, and observability.

Diffusion of Innovation Theory has been widely applied in agricultural extension research because it provides a useful framework for understanding how farmers adopt new technologies and farming practices. Agricultural innovations are typically introduced through extension systems, and farmers decide whether to adopt them based on their perceived usefulness, accessibility, and compatibility with existing farming practices. In the context of digital agriculture, mobile agricultural applications represent technological innovations designed to improve access to agricultural information and enhance farm productivity.

The concept of relative advantage refers to the degree to which an innovation is perceived as being better than existing alternatives. Mobile agricultural applications offer several advantages over conventional extension approaches by providing real-time access to weather forecasts, pest and disease management information, market prices, and agronomic recommendations. These benefits can improve farmers' decision-making processes and reduce information delays (Aker, 2011).

Compatibility refers to the extent to which an innovation aligns with the values, experiences, and needs of potential adopters. Mobile agricultural applications are more likely to be adopted when they address the specific information needs of farmers and fit within their existing farming systems. However, adoption may be constrained when applications are designed without considering local languages, literacy levels, or socio-cultural realities of rural communities.

Complexity describes the degree to which an innovation is perceived as difficult to understand or use. The findings of previous studies indicate that digital literacy remains a significant determinant of technology adoption among rural farmers (Baumüller, 2018). Applications with complicated interfaces, technical language, or multiple navigation requirements may discourage utilization among farmers with limited educational backgrounds.

Trialability refers to the extent to which an innovation can be tested before full adoption. Farmers who have opportunities to experiment with mobile agricultural applications through extension demonstrations, training programs, or pilot initiatives are more likely to develop confidence in the technology and subsequently adopt it. Extension agencies therefore play an important role in facilitating exposure and experimentation with digital agricultural tools.

Observability relates to the visibility of innovation outcomes to potential adopters. When farmers observe tangible benefits such as improved yields, increased profits, better market access, or enhanced communication with extension agents, they are more likely to adopt mobile agricultural applications. Observable positive outcomes encourage knowledge sharing and accelerate technology diffusion within farming communities.

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The relevance of the Diffusion of Innovation Theory to this study lies in its ability to explain variations in the adoption and utilization of mobile agricultural applications among smallholder farmers in Benue State. The theory suggests that farmers' decisions to utilize digital extension platforms are influenced not only by access to smartphones and internet services but also by their perceptions of the usefulness, simplicity, and benefits associated with the technology. Consequently, the theory provides a suitable framework for understanding the factors influencing the adoption of mobile agricultural applications and their contribution to agricultural productivity among smallholder farmers.

CONCEPTUAL FRAMEWORK

The conceptual framework for this study is developed from the Diffusion of Innovation Theory and recent empirical studies on digital agriculture adoption among smallholder farmers. The framework assumes that the utilization of mobile agricultural applications is influenced by a combination of socioeconomic, technological, and institutional factors, which subsequently affect agricultural productivity.

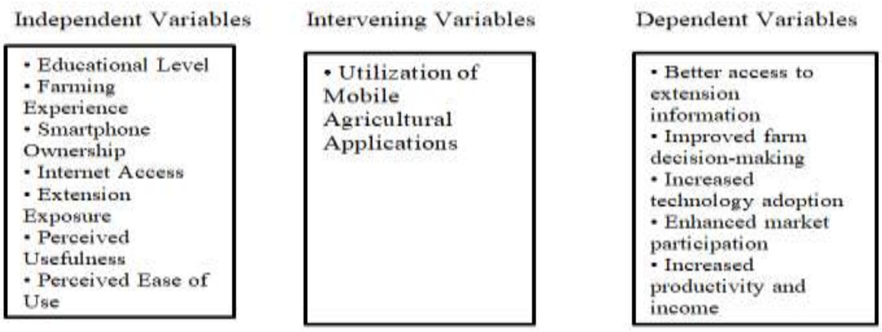
At the socioeconomic level, farmers' educational attainment, farming experience, and exposure to extension services are expected to influence their ability to understand, evaluate, and utilize digital agricultural applications. Farmers with higher levels of education are generally more capable of interpreting digital information and integrating technological recommendations into farm management decisions. Similarly, prior farming experience may shape perceptions regarding the usefulness and practicality of mobile-based agricultural advisory services.

Technological factors constitute another critical component of the framework. Smartphone ownership and reliable internet access are regarded as enabling conditions for digital technology utilization. Since most agricultural applications require internet connectivity and smartphone functionality, farmers who possess these resources are more likely to adopt and regularly utilize digital extension platforms. Recent studies have shown that access to smartphones, network infrastructure, and exposure to digital tools significantly increases the probability of agricultural technology adoption among smallholder farmers.

The framework further incorporates two important behavioural constructs derived from the Technology Acceptance Model (TAM): perceived usefulness and perceived ease of use. Perceived usefulness refers to the extent to which farmers believe that mobile agricultural applications can improve productivity, decision-making, market participation, and access to agricultural information. Perceived ease of use relates to the degree to which farmers consider digital platforms simple to learn and operate. Previous studies indicate that these factors strongly influence adoption decisions among smallholder farmers in Sub-Saharan Africa.

The framework therefore posits that educational level, farming experience, smartphone ownership; internet access, extension exposure, perceived usefulness, and perceived ease of use collectively influence the utilization of mobile agricultural applications. Increased utilization of mobile agricultural applications is expected to improve access to extension information, weather forecasts, market intelligence, pest and disease management recommendations, and modern agronomic practices. Consequently, improved utilization contributes to enhanced farm-level decision-making, increased adoption of improved technologies, and ultimately higher agricultural productivity among smallholder farmers.

Conceptually, the relationship among the study variables can be represented as follows



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METHODOLOGY

Study Area

The study was conducted in Benue State, Nigeria, which is located within the North-Central geopolitical zone. Popularly referred to as the "Food Basket of the Nation" due to its extensive agricultural productivity, the State lies geographically between latitudes **6°25′ North and 8°8′ North**, and longitudes **7°47′ East and 10°0′ East**.

Benue State shares administrative boundaries with Nasarawa State to the north, Taraba State to the east, Enugu State to the south, and Kogi State to the west. Agriculture serves as the primary occupation for the vast majority of the rural population, with smallholder farmers predominantly engaged in cultivating staple and cash crops such as yam, cassava, rice, maize, soybean, and millet. For operational and extension purposes, the State is divided into three distinct agricultural zones: Zone A (Eastern Zone), Zone B (Central Zone), and Zone C (Western Zone). The widespread presence of active farming communities and the growing footprint of mobile telecommunication services made the State an ideal environment for investigating digital agricultural extension services.

Research Design

The study adopted a mixed-methods research design, seamlessly integrating quantitative and qualitative data collection and analytical pathways. The quantitative track prioritized structured questionnaires to gather numerical data from smallholder farmers, while the qualitative track leveraged semi-structured key informant interviews (KIIs) with professional agricultural extension agents. This dual approach is highly effective because it allows researchers to triangulate statistical results against the lived, contextual observations of extension practitioners on the ground (Creswell and Creswell, 2018).

Sampling Technique and Sample Size

A rigorous multi-stage sampling technique was utilized to select respondents.

- **Stage 1:** The three agricultural zones of Benue State (Zones A, B, and C) were purposively selected to ensure complete geographic representation.
- **Stage 2:** Two Local Government Areas (LGAs) were randomly selected from each of the three zones, yielding a total of six LGAs.
- **Stage 3:** Two distinct rural farming communities were randomly chosen from each selected LGA, resulting in twelve farming communities.
- **Stage 4:** A simple random sampling approach was used to select smallholder farmers from official community registers maintained by local cooperative societies. This process yielded a final sample size of **210 smallholder farmers**.

Concurrently, a purposive sampling approach was employed to select **25 agricultural extension agents** active within the sampled LGAs to participate in the key informant interviews, ensuring they possessed direct field experience with both traditional and digital advisory systems.

Data Collection Methods

Primary data collection was executed over a field period using pre-tested tools. The quantitative questionnaire designed for smallholder farmers was structured into distinct thematic modules: socioeconomic profiles, smartphone and internet access characteristics, application utilization frequencies across four core domains, perceived benefits on a 4-point Likert scale, and an itemized constraint matrix.

To ensure instrument validity, the questionnaire was subjected to peer review by senior extension experts at Joseph Sarwuan Tarka University, and a pilot test with 20 farmers outside the sample domain yielded a

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Cronbach's alpha reliability coefficient of 0.82, confirming high internal consistency. The qualitative interview schedule for extension agents focused on institutional digital deployment strategies, network infrastructure realities, and systemic bottlenecks.

Mathematical and Statistical Framework

Descriptive statistics (frequencies, percentages, means, and standard deviations) were utilized to fulfill Objectives 1, 2, and 4.

For Objective 3, inferential statistics were applied. Pearson Product Moment Correlation (PPMC) was employed to test the relationship between the continuous variables of formal education (years of schooling) and application utilization level (aggregated index of use frequency).

To determine which specific socioeconomic and technological factors influence whether a farmer uses mobile applications, a **Binary Logistic Regression Model** was used.

The main thing we are measuring is **Application Utilization (Y)**, which has only two possible outcomes:

- **Y = 1**: The farmer uses mobile agricultural apps regularly (at least once a week).
- **Y = 0**: The farmer does not use the apps regularly (or does not use them at all).

The formula used to calculate this probability is written as:

Logit(P) = b0 + b1(X1) + b2(X2) + b3(X3) + b4(X4) + b5(X5) + b6(X6) + e

Where:

- **Logit(P)** = The log-odds of a farmer regularly utilizing mobile agricultural applications.
- **b0** = The intercept constant of the model.
- **X1** = Age of the farmer (Years).
- **X2** = Gender of the farmer (Dummy variable: Male = 1, Female = 0).
- **X3** = Educational level (Total years of formal education).
- **X4** = Farming experience (Years).
- **X5** = Smartphone ownership (Dummy variable: Owns smartphone = 1, Does not own = 0).
- **X6** = Reliable internet access (Dummy variable: Has reliable access = 1, Lacks reliable access = 0).
- **b1 ... b6** = Regression coefficients to be estimated for each independent variable.
- **e** = the error term representing unobserved real-world factors.

The specific factors (X) being tested are:

- **Age**: The age of the farmer measured in years.
- **Gender**: Grouped as a dummy variable (where Male = 1, and Female = 0).
- **Education**: The total number of years the farmer spent in formal school.
- **Farming Experience**: The number of years the individual has been working as a farmer.

- **Smartphone Ownership**: Grouped as a dummy variable (where owning a smartphone = 1, and relying on a basic phone = 0).
- **Reliable Internet Access**: Grouped as a dummy variable (where having reliable internet = 1, and lacking reliable internet = 0).

RESULTS AND DISCUSSION

Socioeconomic Characteristics of Respondents

The empirical profile of the sampled smallholder farmers demonstrates a highly active workforce with asymmetric access to modern ICT assets. The data in Table 1 reveals that 68% of the surveyed farmers were male, while 32% were female, reflecting a persistent gender disparity in independent farm management and agricultural decision-making across north-central Nigeria. The pooled mean age of the farmers was 41 years (SD = 8.4), showing that the agricultural sector in Benue State is largely sustained by individuals in their prime, economically productive years who are theoretically open to behavioral shifts in technology adoption.

Table 1: Socioeconomic Profile of Smallholder Farmers (n = 210)

Socioeconomic characteristics	Category	Frequency	Percentage (%)	Mean/SD
Gender	Male	143	68.10	
	Female	67	31.90	
Age (Years)	≤ 30	32	15.24	
	31-45	124	59.05	41.00 years
	> 45	54	25.71	SD = 8.8
Marital Status	Married	120	57.14	
	Single/Widowed/divorced	90	42.86	
Education Level	No Formal Education	82	39.05	
	Primary Education	45	21.43	10.2 Years
	Secondary Education	52	24.76	SD = 4.1
	Tertiary Education	31	14.76	
Farming Experience	≤5 years	28	13.33	
	6 – 15 years	132	62.86	13.2 Years
	> 15 Years	50	23.81	SD 5.3
ICT Asset Profile	Own Smartphone	113	53.81	
	Basic/feature phone/none	97	46.19	

About 61% of the respondents possessed formal education ranging from primary to tertiary levels, leaving a substantial 39% completely without formal schooling. This educational split poses a major barrier to the deployment of text-heavy digital extension interfaces. Farming experience averaged 13.2 years, showing a

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strong foundation of traditional agronomic knowledge. Crucially, while 54% of farmers owned an internet-capable smartphone, 46% remain entirely excluded from application-based extension tools due to their reliance on basic feature phones. These structural realities mirror the findings of Baumüller (2018), who noted that the baseline possession of advanced communication hardware and educational capital directly controls the speed and success of digital agricultural innovation adoption.

Level of Utilization of Mobile Agricultural Applications

The empirical assessment of mobile application adoption across specific information domains reveals an uneven utilization pattern (Table 2). While basic extension communication via mobile apps was utilized regularly by 46% of respondents, specialized application features remained vastly underutilized.

Table 2: Domain-Specific Distribution of Mobile App Utilization (n = 210)

Extension Information Domain	Regular Use (Freq)	Regular Use (%)	Non-Regular/ No Use (Freq)	Non-Regular/No Use (%)
General Extension Advisories	**97**	**46.19**	**113**	**53.81**
Weather and Pest Management Updates	**80**	**38.10**	**130**	**61.90**
Real-time Market Price Feeds	88	41.90	122	58.10
Seed Varieties and Fertilizer Apps	73	34.76	137	65.24

Only 38% of farmers actively used specialized applications to track meteorological shifts and pest outbreak models. Market price feeds were regularly monitored by 42% of the sample, which highlights a strong user interest in commercial tracking tools that protect income from middlemen.

Conversely, apps focused on precision input inputs (such as optimized seed selection and fertilizer calculators) recorded the lowest regular usage at 35%. This low adoption rate indicates that farmers lack deep practical training on complex digital interfaces. These findings are consistent with Mittal and Mehar (2016), who reported that the transition from simple mobile communications to complex, application-driven precision agriculture is heavily constrained by structural and user-capacity limits in rural developing economies.

Benefits Derived from Digital Extension Services

Farmers who actively integrated mobile applications into their farming workflows noted clear economic and operational benefits, which are detailed on a ranked Likert scale in Table 3.

Table 3: Perceived Benefits of Mobile Extension Platforms (n = 210)

Perceived Agronomic & Economic Benefit	Mean Score	Standard Dev	Ranking
Improved farming decisions and accelerated technology adoption	3.12*	0.45	1st
Improved farming decisions and accelerated technology adoption	3.12*	0.45	1st
Timely acquisition of localized agricultural information	2.98*	0.61	2nd
Direct access to market opportunities and input price indices	2.84*	0.52	3rd
Reduced delay in communicating with professional extension agents	2.56*	0.73	4th

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Note: Mean scores calculated on a 4-point scale (4 = Strongly Agree, 3 = Agree, 2 = Disagree, 1 = Strongly Disagree). Cut-off mean for agreement ≥2.50.			

The primary advantage cited was the improvement of farm-level decision-making and the accelerated adoption of modern agronomic practices (Mean = 3.12). Respondents reported that having immediate access to information on planting windows, disease-resistant crop varieties, and correct chemical applications reduced their reliance on guesswork.

The timely acquisition of information ranked second (Mean = 2.98), while accessing direct market opportunities and bypassing exploitative local agents ranked third (Mean = 2.84). Finally, shortening the communication loop with professional extension agents was verified as a clear benefit (Mean = 2.56). Qualitative evidence from the key informant interviews with extension agents strongly reinforced these points. Several agents noted that digital channels allowed them to push pest alerts to hundreds of farmers simultaneously, completely bypassing the logistical challenges of rural travel. These empirical trends strongly validate Aker's (2011) foundational position that digital information tools reduce transaction costs and mitigate information gaps across rural farming networks.

Constraints Affecting Mobile Agricultural Application Usage

Despite these clear benefits, smallholder farmers face a complex web of technical, financial, and educational barriers that hinder adoption, as detailed in Table 4.

Table 4: Analytical Matrix of Constraints to Digital Extension Adoption (n = 210)

Identified Operational Constraint	**Frequency**	**Percentage (%)**	**Sample Ranking**
Poor and unstable rural internet connectivity	155	73.81	1st
Prohibitive financial cost of mobile data subscriptions	145	69.05	2nd
Inadequate digital literacy and application interface confusion	132	62.86	3rd
Inability to afford internet-capable smartphones	120	57.14	4th
Erratic electricity grid supply for charging devices	104	49.52	5th

Poor rural internet connectivity was ranked as the top barrier by 74% of respondents. In many rural communities across the three agricultural zones of Benue State, 3G and 4G networks remain highly unstable, resulting in frequent data dropouts during application use. The high cost of data subscriptions ranked second (69%), serving as a major economic deterrent for low-income smallholders.

Low digital literacy ranked third (63%). Many applications feature complex english-only text menus that prove unusable for uneducated farmers. Financial constraints regarding the upfront purchase of smartphones (57%) and unreliable rural electricity grids for device charging (50%) further compound the problem. This clear pattern of constraints corroborates the warnings of Nwafor et al. (2021), who stated that without aggressive institutional support for rural infrastructure, digital agricultural tools run the risk of widening the socioeconomic gap between wealthy and marginalized farmers.

Beyond infrastructural barriers, the findings suggest the existence of broader inclusion challenges that may influence digital extension adoption. Language accessibility remains a significant concern because many agricultural applications are developed primarily in English, limiting usability among farmers with low literacy levels or those who predominantly communicate in indigenous languages such as Tiv, Idoma, and Igede. Similarly, gender-related constraints may affect access to smartphones, internet services, and digital training opportunities, particularly among female farmers who often face resource limitations. These findings underscore the need for inclusive digital extension strategies that accommodate linguistic diversity, varying literacy levels, and gender-specific barriers within rural farming communities.

STATISTICAL ASSOCIATION AND INFERENTIAL ANALYSIS

Correlation Analysis (PPMC)

To test the statistical association between human capital and digital onboarding, a Pearson Product Moment Correlation was executed. The analysis revealed a strong, positive, and statistically significant relationship between a farmer's formal education level (measured in years of schooling) and their frequency of mobile agricultural application utilization ($r = 0.61$, $p < 0.05$). This high correlation value demonstrates that formal education equips farmers with the literacy skills and confidence required to navigate application menus and convert digital recommendations into field-level choices.

Logistic Regression Analysis

The binary logistic regression model provided deep insight into the independent socioeconomic and technological factors driving application utilization. The model achieved a high level of fit, with a Chi-square value significant at $p < 0.01$ and a Nagelkerke R^2 of 0.54, indicating that the included predictors account for 54% of the total variance in utilization behavior.

Table 5: Binary Logistic Regression Parameters for Determinants of Application Use

Explanatory Variable	Estimated Coefficient (β)	Standard Error (S.E.)	Wald Statistic	Probability (p-value)
Constant	-1.24	0.58	4.57	0.032*
Age (X_1)	-0.02	0.01	1.88	0.170
Gender (X_2)	0.14	0.11	1.62	0.203
Education Level (X_3)	0.28	0.09	9.68	0.002**
Farming Experience (X_4)	0.05	0.04	1.56	0.212
Smartphone Ownership (X_5)	0.49	0.15	10.67	0.001**
Internet Access (X_6)	0.37	0.16	5.34	0.021*
Note: ** Significant at $p < 0.01$; * Significant at $p < 0.05$. Chi-square = 48.62; Nagelkerke R^2 = 0.54.				

The regression results in Table 5 indicate that **Smartphone Ownership** ($\beta = 0.49$, $p < 0.01$) is the single strongest predictor of regular application utilization. The positive coefficient shows that owning a smartphone dramatically increases the log-odds of a farmer adopting digital advisory tools. Similarly, **Reliable Internet Access** (**β** = 0.37, $p < 0.05$) significantly increases utilization probability, confirming that stable telecommunication networks are essential for digital platforms to function effectively.

Education Level (**β** = 0.28, $p < 0.01$) was also highly significant, indicating that each additional year of formal schooling significantly boosts a farmer's ability to use digital applications. Conversely, demographic control variables such as age, gender, and raw farming experience did not exert statistically significant direct effects on application usage, emphasizing that technological access and basic literacy are far more critical than age or gender in driving digital agriculture adoption.

CONCLUSION AND RECOMMENDATIONS

Summary of Findings

This study evaluated the adoption of mobile agricultural applications as digital extension tools within Benue State, Nigeria. The empirical findings reveal that while mobile tools offer a promising alternative to traditional extension systems, actual regular utilization remains modest and unevenly distributed. Less than half (46%) of smallholder farmers regularly use digital platforms for general extension updates, and even fewer leverage specialized apps for weather forecasting, market pricing, or precision input calculations.

The findings indicate that mobile agricultural applications have the potential to improve agricultural productivity indirectly through enhanced access to extension information, faster decision-making, improved market intelligence, and greater exposure to modern agronomic practices. While the present study did not directly measure productivity indicators such as crop yield, farm income, or production efficiency, farmers consistently reported that access to timely agricultural information improved their capacity to make informed production and marketing decisions. These outcomes suggest that mobile agricultural applications can serve as important enablers of productivity improvement when supported by adequate infrastructure, digital literacy, and extension services.

Practical Implications

The practical implications of these findings for policymakers, extension administrators, and technology developers are substantial. First, the study demonstrates that digital tools cannot simply be deployed under the assumption that rural users will automatically adopt them. Without intentional intervention, digital extension systems risk creating a "digital divide," where educated, well-connected farmers maximize their yields while marginalized, illiterate smallholders drop further behind. To build a resilient agricultural advisory framework, digital tools must be treated as complements to rather than complete replacements for human extension personnel. Furthermore, applications must be structurally redesigned to match the actual literacy levels and hardware realities of rural users.

Study Limitations

Despite the valuable insights generated by this study, certain limitations should be acknowledged. First, the study was geographically confined to Benue State, Nigeria. Although Benue State represents one of the country's major agricultural regions, the findings may not be fully generalizable to other states or regions characterized by different socioeconomic, infrastructural, cultural, and technological conditions.

Second, the study relied primarily on self-reported responses from farmers regarding mobile application utilization, perceived benefits, and operational constraints. Self-reported data may be influenced by recall errors, social desirability bias, or respondents' tendency to overestimate their actual technology usage and productivity gains.

Third, while the study examined mobile agricultural applications collectively as digital extension tools, it did not conduct a comparative evaluation of individual applications. Consequently, differences in platform functionality, user interface design, language support, reliability, and effectiveness could not be assessed.

Finally, the study focused primarily on utilization patterns and determinants of adoption rather than objective measurements of productivity outcomes such as crop yield changes, farm income growth, input-use efficiency, and profitability. Future studies should incorporate longitudinal and farm-level performance indicators to establish stronger causal evidence regarding the impact of mobile agricultural applications on agricultural productivity.

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Future Research Directions

Future research should move beyond measuring adoption and utilization to evaluating the actual productivity effects of mobile agricultural applications. Researchers should incorporate objective indicators such as crop yield per hectare, farm income, production efficiency, input-use optimization, and market participation outcomes to provide stronger empirical evidence of technology impacts.

Further studies should also undertake comparative assessments of specific agricultural applications used by Nigerian farmers. Such investigations would help identify platform characteristics that most effectively support decision-making, including localized content delivery, weather forecasting accuracy, market information services, pest and disease management functions, and ease of use.

Additionally, greater attention should be devoted to understanding the influence of digital literacy, affordability of internet services, local-language accessibility, gender disparities, and age-related differences in technology adoption. Addressing these factors would contribute to the development of more inclusive digital extension systems capable of serving diverse categories of smallholder farmers across Nigeria and Sub-Saharan Africa.

Recommendations

To address these challenges and maximize the impact of digital extension tools, the following recommendations are proposed:

1. **Strategic Infrastructure Investment:** The Federal Ministry of Communications, Innovation and Digital Economy, in partnership with private telecommunications firms, should invest in upgrading rural cell tower networks to provide stable, low-latency 4G connectivity across farming communities in Benue State.

2. **Targeted Digital Literacy Campaigns:** Agricultural extension agencies, such as BNARDA, should launch localized training programs focused on teaching farmers how to download, interpret, and act on data within agricultural application interfaces.

3. **Financial Support Programs:** The Bank of Agriculture (BOA) and local cooperative unions should set up micro-credit facilities to help smallholder farmers purchase affordable, internet-capable smartphones, coupled with subsidized data bundles tailored for registered agricultural platforms.

4. **User-Centric Application Design:** Software engineers and agricultural tech developers must redesign application interfaces to include local languages (such as Tiv, Idoma, and Igede), voice-guided audio prompts, and icon-based navigation to make tools fully accessible to uneducated farmers.

5. **Institutional Alignment and Policy Integration:** The Benue State Ministry of Agriculture should formalize a comprehensive digital extension policy framework that encourages co-funding and data sharing between state extension agents, local university researchers, and private agritech companies.

6. **Development of Inclusive and Localized Digital Platforms:** Agricultural technology developers should prioritize the integration of indigenous language options, voice-assisted interfaces, offline functionality, and gender-responsive design features to ensure that mobile agricultural applications remain accessible to diverse categories of smallholder farmers regardless of literacy level, income status, or geographic location.

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