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Effectiveness of digital agricultural extension services in promoting climate-smart farming practices among smallholder farmers in northern Ghana

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Abstract

Climate change threatens agricultural productivity and food security among smallholder farmers in sub-Saharan Africa, demanding urgent adoption of climate-smart agriculture (CSA) practices. This study assessed the effectiveness of digital agricultural extension services in promoting CSA practices among 384 randomly selected smallholder farmers across three districts of Northern Ghana using a cross-sectional survey design. Descriptive statistics, chi-square (χ^2) tests, binary logistic regression, and independent-samples t-tests were employed. Results indicated that 67.4% of respondents accessed at least one digital extension service, with mobile phone-based advisory services most prevalent (74.2%). CSA adoption was significantly higher among digital extension users than non-users (68.7% vs. 31.8%; $p < 0.001$). Digital extension access emerged as the strongest predictor of CSA adoption (OR = 3.21; 95% CI: 2.14-4.81; $p < 0.001$), followed by smartphone ownership (OR = 2.45; $p < 0.001$) and farmer group membership (OR = 2.11; $p < 0.001$). Maize yields were 22.6% higher and annual farm income 32.4% higher among digital extension users. The study concludes that digital extension services significantly accelerate CSA adoption and recommends scaling digital infrastructure, strengthening digital literacy, and embedding gender-sensitive strategies to maximise reach across Northern Ghana.

Keywords: Digital extension; climate-smart agriculture; smallholder farmers; Northern Ghana; technology adoption; food security

Introduction

Climate change poses escalating threats to agricultural productivity in sub-Saharan Africa, with smallholder farmers in Ghana bearing disproportionate burdens agriculture employs 52% of the national workforce and contributes 22.9% to GDP [3, 19]. Northern Ghana is especially vulnerable to erratic rainfall, prolonged droughts, and soil degradation, all of which suppress yields among rain-fed smallholder systems [2, 10, 18]. Climate-smart agriculture (CSA) encompassing drought-tolerant varieties, conservation tillage, improved soil and water management, and agroforestry offers a proven framework for simultaneously enhancing productivity, building resilience, and mitigating emissions [1, 3, 14]. However, CSA uptake in Northern Ghana remains persistently low, constrained by inadequate conventional extension systems characterised by infrequent farm visits, top-down communication, and poor geographic reach [7, 9, 17]. The proliferation of mobile telephony and ICTs creates scalable opportunities for digital agricultural extension including SMS advisories, mobile applications, community radio, and WhatsApp networks to bridge this advisory gap and accelerate technology adoption [4, 5, 6]. Evidence from comparable sub-Saharan contexts confirms that ICT-mediated information delivery reduces adoption barriers and improves farming decisions [11, 21]; however, robust empirical evidence quantifying digital extension effectiveness specifically for CSA promotion in Northern Ghana is absent [9, 10, 17]. Moreover, the digital divide threatens to exclude marginalised farmers particularly women and the elderly from advisory benefits [15, 16, 20], and limited gender-disaggregated research constrains inclusive policy design [21, 22]. This study therefore assessed access to digital extension services, examined their effectiveness in promoting CSA adoption, identified adoption determinants, and quantified yield impacts among smallholder farmers in Northern Ghana [8, 12, 13]. It was hypothesised that digital extension users would

exhibit significantly higher CSA adoption rates and agricultural productivity than non-users [8, 12, 13, 14, 15].

2. Material and Methods

2.1 Material

The study was conducted in Tolon, Kumbungu, and Savelugu-Nanton districts of the Northern Region of Ghana, selected for their predominant smallholder farming systems and documented climate vulnerability [9, 10]. The region experiences a unimodal rainfall regime of 900-1,100 mm annually; principal crops include maize, sorghum, groundnuts, millet, and rice cultivated on plots averaging 1.5 ha under rain-fed conditions [9, 19]. A cross-sectional survey design was adopted [22]. The sample size of 384 was derived using the Yamane (1967) formula for a finite population of approximately 12,400 farming households at 95% confidence and $\pm 5\%$ margin of error. Three-stage sampling was employed: purposive district selection, random community selection (12 communities; 4 per district), and systematic household selection within each community [8, 22]. Structured questionnaires, pre-tested on 38 farmers, captured digital extension access, adoption of seven CSA practices, and agricultural outcome indicators. Interview guides facilitated key informant discussions with district extension officers and farmer group leaders [7, 11].

2.2 Methods

Data collection was conducted over ten weeks (January-March 2024) by ten bilingual (English/Dagbani) trained enumerators. Data were entered in CSPro 7.6, verified for consistency, and exported to IBM SPSS Statistics 26.0 for analysis. Descriptive statistics characterised respondent profiles and digital extension access patterns [11]. Pearson's chi-square (χ^2) tests examined associations between digital

extension access and adoption of each CSA practice ($p < 0.05$)^[22]. Binary logistic regression with CSA adoption status (adopter = 1; non-adopter = 0) as the dependent variable and nine socioeconomic predictors identified adoption determinants; model fit was assessed via Nagelkerke R^2 , Hosmer-Lemeshow test, and classification accuracy^[12, 13]. A composite CSA adoption index (mean proportion of seven practices adopted) enabled continuous-outcome comparisons^[4, 14]. Independent-samples t-tests compared mean yields, income, and food security scores between digital extension users and non-users^[8]. Ethical clearance was obtained from the UDS Institutional Review

Board (UDS-IRB/2024/012), and written informed consent was secured from all participants^[5].

3. Results

3.1 Sociodemographic Characteristics

Table 1 presents the sociodemographic profile of respondents. Most were male (64.6%), aged 31-45 years (40.6%), with Middle/JHS education (32.3%), farming 1-2 ha (43.8%), and a mean farming experience of 14.3 ± 7.2 years. Farmer group membership (57.0%) and smartphone ownership (48.7%) were moderately prevalent, consistent with observed patterns in Northern Ghana^[9, 16].

Table 1: Sociodemographic characteristics of respondents (n = 384)

Characteristic	Category	Frequency (n)	Percentage (%)
Gender	Male	248	64.6
	Female	136	35.4
Age (years)	18-30	62	16.1
	31-45	156	40.6
	46-60	118	30.7
	>60	48	12.5
Education level	No formal education	89	23.2
	Primary	102	26.6
	Middle/JHS	124	32.3
	Secondary and above	69	18.0
Farm size (ha)	< 1	97	25.3
	1-2	168	43.8
	> 2	119	31.0
Farmer group membership	Yes	219	57.0
	No	165	43.0
Smartphone ownership	Yes	187	48.7
	No	197	51.3
Mean farming experience (years)	-	14.3 ± 7.2	-

3.2 Access to digital extension services

Overall, 67.4% (n = 259) of respondents accessed ≥ 1 digital extension service (Table 2). Mobile SMS/voice advisory was the most accessed platform (74.2%), while community radio recorded the highest satisfaction score (4.1/5.0). E-extension radio recorded the highest satisfaction score (4.1/5.0). E-

extension portals had the lowest uptake (14.1%), reflecting limited internet connectivity and digital literacy constraints in the study area^[6, 16]. Figure 1 illustrates comparative CSA adoption rates by digital extension access status^[4, 5].

Table 2: Access to digital agricultural extension services by type (n = 384)

Type of Digital Extension Service	Users (n)	Usage Rate (%)	Satisfaction (1-5)
Mobile phone advisory (SMS/voice)	285	74.2	3.9
Community radio ICT programmes	221	57.6	4.1
Television agricultural broadcasts	189	49.2	3.7
WhatsApp/social media farmer groups	167	43.5	4.0
Agricultural mobile applications	142	37.0	3.4
Internet-based platforms/websites	98	25.5	3.2
E-extension portals	54	14.1	3.1
Total: access to ≥ 1 service	259	67.4	-

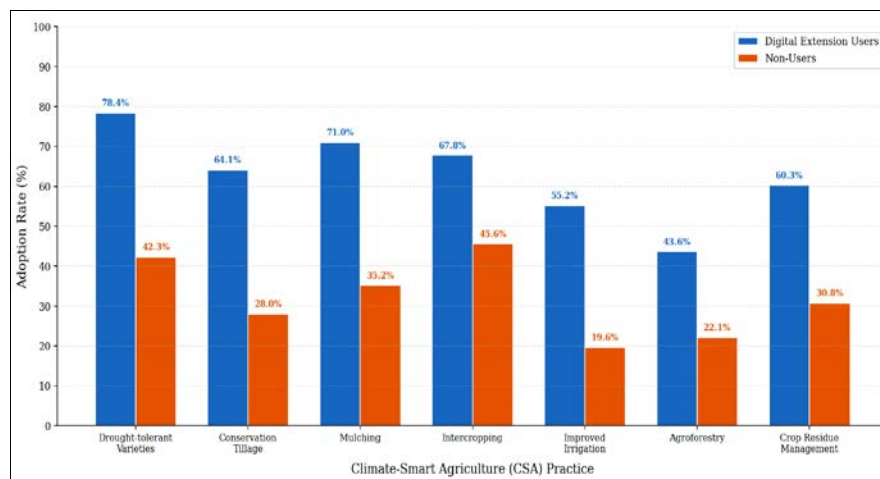


Fig 1: Adoption rates of CSA practices by digital extension access status among smallholder farmers in Northern Ghana

3.3 CSA adoption by digital extension access status

Significant differences were observed across all seven CSA practices (all $p < 0.001$; Table 3). The largest differentials were for drought-tolerant varieties (78.4% vs. 42.3%) and

improved irrigation management (55.2% vs. 19.6%). The overall CSA adoption index was markedly higher among digital extension users (68.7% vs. 31.8%; $\chi^2 = 61.92$; $p < 0.001$)^[11, 14, 17].

Table 3: Adoption of CSA practices by digital extension access status

CSA Practice	Digital Users (%)	Non-Users (%)	χ^2	p-value
Drought-tolerant varieties	78.4	42.3	54.21	<0.001
Conservation tillage	64.1	28.0	48.37	<0.001
Mulching	71.0	35.2	42.09	<0.001
Intercropping	67.8	45.6	18.73	<0.001
Improved irrigation & soil water mgmt.	55.2	19.6	52.84	<0.001
Agroforestry	43.6	22.1	22.17	<0.001
Crop residue management	60.3	30.8	36.45	<0.001
Overall CSA adoption index	68.7	31.8	61.92	<0.001

Note: χ^2 = Pearson chi-square statistic; all p-values from two-tailed tests; significance threshold $p < 0.05$

3.4 Determinants of CSA adoption

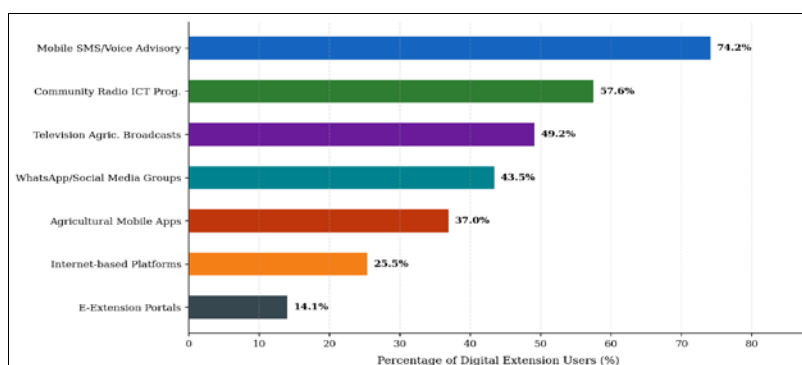
The logistic regression model was highly significant ($\chi^2(9) = 184.26$; $p < 0.001$; Nagelkerke $R^2 = 0.461$; classification accuracy = 81.3%; Hosmer-Lemeshow: $p = 0.449$; Table 4). Digital extension access was the strongest positive predictor (OR = 3.209; $p < 0.001$), followed by smartphone ownership

(OR = 2.450; $p < 0.001$) and farmer group membership (OR = 2.113; $p < 0.001$). Age (OR = 0.959; $p = 0.020$) and distance to extension offices (OR = 0.918; $p = 0.011$) were significant negative predictors. Figure 2 contextualises the reach of each digital service type [8, 12, 13].

Table 4: Binary logistic regression: determinants of CSA adoption (n = 384)

Variable	β	SE	Wald χ^2	OR	95% CI	p-value
Age (years)	-0.042	0.018	5.44	0.959	0.925-0.994	0.020
Education level	0.384	0.097	15.65	1.468	1.213-1.777	<0.001
Farm size (ha)	0.217	0.104	4.36	1.242	1.013-1.523	0.037
Smartphone ownership	0.896	0.213	17.70	2.450	1.615-3.719	<0.001
Digital extension access	1.166	0.207	31.70	3.209	2.140-4.813	<0.001
Farmer group membership	0.748	0.201	13.87	2.113	1.424-3.135	<0.001
Household size	0.089	0.052	2.93	1.093	0.987-1.211	0.087
Gender (Female = 1)	0.312	0.198	2.48	1.366	0.927-2.013	0.115
Distance to ext. office (km)	-0.086	0.034	6.39	0.918	0.859-0.981	0.011
Constant	-2.314	0.612	14.27	-	-	<0.001

Note: OR = odds ratio; SE = standard error; 95% CI = 95% confidence interval; Nagelkerke $R^2 = 0.461$; H-L test: $\chi^2(8) = 7.84$, $p = 0.449$; Classification accuracy = 81.3%

**Fig 2:** Distribution of digital agricultural extension service types accessed by smallholder farmers (% of digital extension users, n = 259)

3.5 Impact on agricultural outcomes

Digital extension users achieved significantly higher yields and income across all indicators (Table 5). Maize yield was 22.6% higher (1,847 vs. 1,506 kg/ha; $t = 11.23$; $p < 0.001$),

annual farm income 32.4% higher (GHS 4,820 vs. 3,640; $t = 10.67$; $p < 0.001$), and the food security score was meaningfully better (7.8 vs. 5.6; $t = 13.78$; $p < 0.001$) among digital extension users relative to non-users [3, 18, 19].

Table 5: Impact of digital extension access on agricultural outcome indicators

Outcome Indicator	Digital Ext. Users	Non-Users	Mean Diff.	t-statistic	p-value
Maize yield (kg/ha)	1,847 $\pm$ 312	1,506 $\pm$ 287	341	11.23	<0.001
Groundnut yield (kg/ha)	894 $\pm$ 198	712 $\pm$ 176	182	9.41	<0.001
Sorghum yield (kg/ha)	1,124 $\pm$ 241	932 $\pm$ 219	192	8.12	<0.001
Annual farm income (GHS)	4,820 $\pm$ 1,142	3,640 $\pm$ 984	1,180	10.67	<0.001
Food security score (0-12)	7.8 $\pm$ 1.4	5.6 $\pm$ 1.7	2.2	13.78	<0.001

Note: Values expressed as mean $\pm$ SD; GHS = Ghanaian Cedi; Food security score uses HFIAS-adapted composite index (range 0-12; higher = better)

4. Discussion

The significantly higher overall CSA adoption among digital extension users (68.7% vs. 31.8%) corroborates sub-Saharan evidence that ICT-mediated advisory services reduce information costs and accelerate technology uptake

[4, 11]. The dominance of mobile SMS/voice advisory (74.2%) aligns with Aker [4] and Nakasone *et al.* [5], who documented mobile telephony's cost and accessibility advantages in rural extension contexts. Community radio's highest satisfaction score (4.1/5.0) reflects its cultural

resonance and local-language accessibility, consistent with Zossou *et al.* [21]. The low uptake of e-extension portals (14.1%) mirrors GSMA [16] and Tsan *et al.* [6] findings on persistent internet connectivity constraints in rural sub-Saharan Africa, underscoring the need for offline-compatible advisory tools. Binary logistic regression confirmed digital extension access as the strongest adoption predictor (OR = 3.21), with farmer group membership (OR = 2.11) reinforcing Davis *et al.*'s [8] evidence on social learning amplification through collective platforms. The positive education effect [12, 13] and negative age effect [12, 22] are well-established in adoption literature. Smartphone ownership (OR = 2.45) signals a growing device-as-gateway dynamic in digital extension [6, 16]. The 22.6% maize yield premium and 32.4% income advantage among digital extension users are consistent with Wiredu *et al.* [10] and Anang *et al.* [9] from comparable Northern Ghana settings. Gender disparities in digital service access echo Zossou *et al.* [21] and Mapila *et al.* [22], emphasising urgent need for gender-targeted digital extension design. The negative distance effect corroborates Birner *et al.*'s [7] call for restructuring extension systems to overcome geographic access barriers [1, 18].

5. Conclusion

This study provides robust evidence that digital agricultural extension services significantly accelerate adoption of climate-smart farming practices and improve agricultural productivity among smallholder farmers in Northern Ghana, with digital extension users recording over twice the CSA adoption rate of non-users and meaningful yield and income advantages across maize, groundnut, and sorghum systems. Digital extension access, smartphone ownership, farmer group membership, and education were the principal drivers of CSA adoption, while age and distance to extension offices constitute the primary structural barriers. To maximise the potential of digital extension, policymakers must prioritise expanding mobile network coverage and rural internet infrastructure, especially for geographically isolated farming communities. Digital literacy programmes in local languages Dagbani, Frafra, and Waale delivered through farmer groups and community radio must accompany technology deployment to ensure effective platform navigation. Gender-responsive strategies including women-only digital literacy training and female peer extension agents are essential to counteract disproportionate exclusion of female farmers from digital advisory networks. Farmer groups should be strategically engaged as primary delivery partners to amplify reach through social learning. The Ghana Ministry of Food and Agriculture, alongside development partners, should resource an integrated National Digital Agricultural Extension Strategy for Northern Ghana combining climate forecasting, market information, soil advisories, and CSA guidance within a unified platform. Routine monitoring and adaptive management frameworks are indispensable to optimise programme design, sustain investment, and underpin a new era of climate-resilient smallholder agriculture across the region.

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