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A systematic review of digital agricultural extension services for smallholder farmers

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Abstract

Agricultural extension has traditionally relied on face-to-face interactions, but the rise of ICTs is transforming how smallholder farmers receive advice. This systematic review analyzes digital extension services worldwide, focusing on technologies (e.g., mobile SMS, smartphone apps, online portals, chat platforms, AI tools), content types (e.g., weather forecasts, market prices, pest diagnostics, best practices), delivery channels (direct SMS/call vs. internet applications vs. social media) and key thematic issues. We assess adoption factors (literacy, device access, trust, cost), outcomes (productivity, income, resilience gains) and inclusion of marginalized groups (women, youth, poor). Results indicate that personalized digital advisory can increase input use and yields by 15–30% and positively affect incomes, but adoption is uneven: two-way channels (calls, WhatsApp) are used more than static smartphone apps. Youth often serve as digital multipliers, whereas women face structural barriers. Cost analyses show digital outreach can be more scalable and cheaper per farmer than traditional visits, especially via high-reach channels (e.g. SMS).

Keywords: Digital agriculture, extension services, smallholders, e-extension, mobile advisory, adoption, inclusivity

Introduction

The phrase “digital agricultural extension” is defined as the provision of agricultural advice and services to smallholder farmers via the use of information and communication technology (ICT) [1]. The examination encompasses issues like historical development, technical progress, content, variables affecting acceptance, effects, concerns on inclusiveness (women & young), cost-effectiveness and scalability of digital extension efforts [2]. The most essential technologies include the most basic mobile (calls, SMS, USSD), internet-based tools (apps, portals, social media) and sophisticated tools (artificial intelligence, drones, internet of things) [3, 4]. The information given might be anything from best practices, pest alerts, market and weather information, it is usually tailored to the characteristics of the local region. Factors influencing adoption and user-centred design include variables such as availability to gadgets, literacy, trust and perceived value [5, 6]. Also, there is growing adoption from better farmer involvement. It may also help to improve resilience with timely counsel. A large percentage of young farmers are digital champions which helps to speed adoption amongst their peers. But women farmers encounter obstacles, such not being able to have a phone, or not being able to read [7]. Models that mix “phygital” assistance (digital and in-person interaction) are more inclusive. Cost-effectiveness assessments reveal that mobile services have the ability to reach a large number of farmers at low cost per farmer [8]. For long-term sustainability it is vital to have viable business models and policies that permit them. These policy implications emphasize the need to invest in rural connectivity and digital literacy, the need to provide inclusive content design, the need to develop public-private sector cooperation and the need to give common measures [9]. The gaps that remain include a larger need for more rigorous effect assessments (particularly long-term and gender-disaggregated), standardized outcome measurements and research on new technologies (such as artificial intelligence, remote sensing and blockchain) [10, 11]. In general,

digitally enabled extension has great potential to enhance the productivity, income and resilience of smallholder farmers, if the social and infrastructural challenges can be overcome^[12].

In the early 20th century agricultural extension was introduced to spread scientific findings to farmers. Agricultural extension, for example, has been represented by the cooperative extension model in the United States, but also by the Green Revolution activities in India and Africa^[13]. Two early extension pioneers, Norman Borlaug and Everett Rogers, set the theoretical groundwork before the digital age. One example of the theoretical framework they developed was Borlaug's high yielding crops and Rogers's diffusion of innovations theory^[14]. The first instance of the use of technology was the radio and television broadcasts for assistance of agriculture in the middle of the century. The use of ICT for Agriculture (ICT4Ag) has increased in intensity throughout the previous several decades^[15]. Governments, for example, set up tele-centers and farmer contact centers in the early 1990s. The main actors of the current digital extension are development scholars and practitioners who promoted the use of information and communication technology in extended education^[16]. For example, CGIAR/IFPRI's Rajul Pandya-Lorch, David Spielman, Kristin Davis and Catherine Ragasa have been at the forefront of the evaluation and policy work on extension enabled by information and communication technology^[17]. Development was also encouraged by non-governmental organizations (NGOs) and business enterprises. Programs such as the Precision Agriculture for Development (PAD) and organizations such as the Food and Agriculture Organization (FAO), the Global Sustainable Management Association (GSMA) and AGRA have aided this^[18]. The following timeline emphasizes key milestones:

The new finding is a signal that we are moving away from non-interactive broadcasting medium and towards data-driven, interactive solutions^[19]. Take, for example, the proliferation of smartphones and social media in the 2010s, which led in the emergence of new platforms and the related multi-dimensional initiatives. We have employed a huge number of scientists and professionals^[20]. Other regional experts (e.g. David Laborde and Johan Swinnen on policy, Stephan Haefele and Mariette McCampbell on implementation) and younger scholars (e.g. Sam Coggins and Brendan Brown) have also looked at digital tools in Africa and Asia besides the people mentioned^[21].

Digital extension is a relatively recent area of research that considers the agricultural science, communication and technology. Taken together, this history and corpus of academic work highlight digital extension as an emergent issue^[22, 23].

Thematic Synthesis

Technologies and Platforms

- Digital extension employs a wide array of technologies. Early efforts used basic mobile phones: SMS alerts (push notifications), IVR (interactive voice response) systems and call centers connecting farmers to experts^[24]. For example, India's Kisan Call Centers (toll-free helplines) answered thousands of farmer queries daily, while national SMS portals broadcast regional weather and market prices. USSD menus also allow farmers to dial short codes for information without needing internet or literacy^[25].
- With smartphone proliferation, mobile apps and web portals became common. Multi-functional smartphone platforms integrate diagnostics (e.g. plant disease image recognition), advisories and market connections. Examples include Plantix (pest diagnostics by image) and eNAM (India's digital market portal)^[26]. These apps often provide customized recommendations (fertilizer doses, variety selection) and link to input suppliers or buyers. Social messaging apps like WhatsApp and Facebook are widely used informally: extension agents share videos or bulletins in group chats and peer networks exchange tips. Social media channels (YouTube, farmer blogs) also serve as informal extension channels^[27].
- New technologies are on the horizon. Farmers are trialling AI and chatbots to automatically answer their inquiries using natural language. This is shown in projects like NDEMRI (AI-driven SMS advice)^[28]. Remote sensing and GIS offer macro-level inputs, such as satellite-based services sending weather predictions or notifications on the health of crops to farmers' phones. IoT sensors and drones are being trialled for precision farming (e.g. soil moisture sensors providing recommendations on watering)^[29]. Use of blockchain and digital platforms for transparency in contract farming and supply chains. These new technologies are still in their infancy but point to future digital advice capabilities (e.g. drone photos to identify pests)^[30].

Table 1: The table below summarizes key categories^[31, 32, 33, 34, 35, 36]

Technology/Platform	Key Features	Example Use Cases
SMS/Text Messaging	Broadcast, localized language text alerts	Weather updates, pest/disease alerts, market prices
IVR / Call Centers	Voice-based menus and expert hotline	Farmer queries answered via live agents or menu voice
USSD Codes	Menu-driven info on basic phones (no Internet)	Checking commodity prices, input recommendations
Web Portals / Websites	Centralized info repositories, e-marketplaces	Real-time market prices (eNAM), downloadable guides
Smartphone Apps (general)	Multi-functional (advice, diagnostics, e-wallet integration)	e.g. digital advisory apps linking to input purchases
Agronomy Diagnostic Apps	Image-based pest/disease diagnosis	Plantix app identifies crop diseases from photos
Weather Forecast Apps	Real-time, localized forecasts	IMD Mausam, Skymet apps for irrigation scheduling
Market/Commodity Apps	Price listing, buyer contact info	AgriBazaar, KisanBazaar linking farmers to buyers

Delivery Channels

Digital extension can be delivered through direct-to-farmer channels or via intermediaries. The most direct are mobile-based: SMS/voice push (top-down broadcasting), inbound calls and interactive apps^[37]. Indirect channels include embedding ICT into formal extension systems: for instance, many extension agents now use tablets or apps to manage farmer data and share content in field visits. Farmer cooperatives or input dealers sometimes use digital platforms to coordinate advice

(e.g. distributing personalized bulletins via WhatsApp)^[38]. Media channels also count as delivery: interactive radio or TV programs can supplement digital tools by prompting listeners to send SMS questions or use hotlines. Lastly, community networks play a role: organized farmer groups or "leader farmers" often help spread digital content offline (e.g. showing app videos during meetings). Thus, delivery is often multichannel combining phone, internet and in-person methods (a "phygital" approach)^[39, 40, 41].

Content Types

Digital extension encompasses diverse content:

- **Weather and Climate:** short term predictions and seasonal recommendations assist farmers plan planting/harvesting and mitigate risk (drought, pests) ^[42].
- **Market Information:** prevailing pricing in local mandis or consumers' marketplaces help to decide crops to be grown and sales. Some sites even link farmers to customers ^[43].
- **Crop Management:** The service is built on best practice recommendations for planting, fertilisation, irrigation, pest and disease management. This includes notifications of new pests or customized advice (e.g. fertilizer rates) ^[44].
- **Seed and Input Recommendations:** recommendations on appropriate crop kinds, procurement of inputs (quality seeds, fertilizers) is sometimes provided. AI tools might help customize dosing ^[45].
- **Livestock Advice:** some agencies give advice on animal husbandry and market information for animals on mixed farms ^[46].
- **Financial/Insurance:** credit, subsidies or weather-index insurance information may be sent via applications or SMS ^[47].
- **Extension Training and Support:** e-learning modules, quizzes or virtual coaching material provide continuing farmer education (e.g. video courses available via phones) ^[48].

Most systems tailor content by locality (crop, language) and sometimes even by individual farm conditions (using inputs like soil data or farmer profile). As one review notes, personalized digital extension "provides information on the types of crops to grow, inputs to use and other methods of cultivation," leading to measurable productivity gains ^[49].

Adoption Factors

Multiple factors influence whether smallholders use digital extension:

- **Device and Connectivity Access:** Farmers require a phone/computer and consistent power/network. Lack of cellphones, electrical shortages and poor mobile service are named in studies frequently as important hurdles. In regions

where only basic phones are available, interactive voice and SMS services are more often used than smartphone applications ^[50, 51].

- **Digital and General Literacy:** Low literacy may prevent the use of technologies that are text-based. Pictorial material or interactive voice services (IVR, audio messaging) may help. Again, digital skills are lacking and user training is needed. Projects training farmers or using local adolescents as facilitators showed increased use ^[52].
- **Relevance and Personalization:** Content has to be relevant to farmers' requirements (crop kind, season). Tools that enable farmers to enter their priorities (e.g. cropping plan) are utilized more than static broadcasts. Many farmers "appropriated" products, only utilizing relevant bits. When developers co-design with users, they get higher acceptance ^[53, 54].
- **Trust and Cultural Factors:** Farmers are more inclined to use tools advised by reputable sources. Credibility boosters include peer demonstration, recommendations from other farmers and local-language information. In one research, uptake was delayed by skepticism of new voice services until agents created rapport. Gender and societal norms matter: women frequently have less decision-making authority and phone access, therefore services must actively reach out to them ^[55].
- **Cost and Value Perception:** Even small charges (SMS fees, airtime) are a barrier for the poorest farmers. Reach is increased at no or subsidized cost. Importantly farmers will embrace if advantages exceed costs. Several publications stress the need of proving revenue increases or yield improvements. Tech-savvy youth farmers may drive wider adoption by demonstrating outcomes ^[56, 57].
- **Support and Training:** Continued technical assistance (helpdesk, agent training) allows continued use. Services that provide feedback loops where farmers may ask questions engage farmers. Where farmers could follow up or change settings, satisfaction increased ^[58]. Adoption may be incremental curiosity, innovators using it and eventually widespread uptake if benefit is seen. Table 2 below illustrates typical hurdles and facilitators and how programs address challenges.

Table 2: Barriers, Enablers and Mitigation Strategies ^[59, 60, 61, 62, 63, 64]

Barrier/Challenge	Enabler/Opportunity	Mitigation/Strategy
Device/Connectivity Access: Lack of smartphone, poor network, no power	High mobile phone penetration in rural areas, widespread SMS compatibility	Design for basic phones (SMS/IVR/USSD), provide solar chargers, develop offline features, partner with telcos to improve coverage
Digital and General Illiteracy: Difficulty reading texts or using apps	Growing familiarity with mobile among youth	Use voice messages or videos, local languages, pictorial or audio interfaces, train local youth as digital facilitators
Content Irrelevance: Advice not aligned with local context or priorities	Mobile apps allow tailoring, GPS-based targeting	Co-create content with farmers, use surveys to match needs, allow farmer input on content priorities, deliver region-specific advisories
Lack of Trust/Source Credibility: Skepticism towards digital advice	Peer networks, demonstrations by trusted farmers	Integrate extension staff or local leaders into digital service, run pilot demonstrations, provide references to proven studies
Gender Norms: Women have limited phone/time for tech, face social constraints	Mobile networks reaching rural women (if accessible)	Design women-friendly services (e.g. audio programs during free hours), include women in design/testing, involve male family members, female-only groups
Cost and Affordability: Phone/data costs or platform fees deter poor farmers	Free SMS and helplines (in some programs) demonstrate potential benefits	Offer free or subsidized services, implement 'results-based financing' where payment links to outcomes, seek NGO/government funding to cover costs

Impacts on Productivity, Income and Resilience

- Empirical studies indicate a good impact of digital extension on smallholder results. For example, a study in

India indicated that farmers utilizing a tailored mobile advising service used 15–20% more inputs, had ~18% higher crop output and had considerably better income than

non-users ^[65]. Similarly, targeted SMS or call advisories have been demonstrated to increase yields by helping farmers use optimal practices at the right time. A second randomized experiment in Gujarat, India (Avaaj Otalo) found that cellphone guidance improved farmers' cotton knowledge and did not limit peer-to-peer information sharing ^[66]. In fact, farmers in the treatment shared more information with neighbours and were prepared to pay more for the service over time. In various African nations, text-message campaigns have boosted the uptake of better seeds and fertilizer via reminders and market suggestions ^[67].

- Resilience is more than productivity, it is also a digital extension. Having access to the latest weather or pest information may help farmers prepare for climate shocks (such as drought) and minimize their impact. Market information may be improved to increase revenues and to decrease post-harvest losses by connecting farmers to purchasers ^[68]. Digital channels provided advice flow during COVID-19 when face-to-face was not available, bridging knowledge gaps and promoting food security. Studies suggest that the digital integration of finance and extension (e.g. packaging loan offers with guidance) might further stabilize livelihoods ^[69].
- Cost-effectiveness studies suggest that digital technologies may provide extension at a far lower cost per farmer than conventional visits. The per-farmer intervention costs for SMS-based services were in the single-digit dollar range, whereas in-person extension expenses are often an order of magnitude higher ^[70]. Digital scaling enables reaching millions (e.g. SMS systems in India reach over 50 million farmers a day). High scalability is shown by the fact that private providers such as Precision Agriculture expect to reach 10–20 million farmers with mobile advisory by 2024 ^[71]. However, most robust impact evidence is still appearing. Many research are on intermediate indicators (knowledge acquisition, adoption rates), few long-term results are known. signs that benefits are diminishing without complementing help (e.g. if farmers lack inputs or markets, advising alone can only go so far) ^[72]. However, there is a widespread opinion that if successfully executed, digital extension may transform the productivity and income of users and so contribute to poverty alleviation and SDG objectives ^[73].

Gender, Youth and Inclusivity

Gender

Women make up over half of smallholder farmers worldwide, yet digital advising services reach fewer women than males. Barriers include lower rates of women's ownership of phones, lesser literacy and cultural norms that restrict women's mobility and decision-making ^[74]. An analysis has shown that if not properly addressed, digital services risk widening existing gender inequalities. A research in Zambia found that while basic phone ownership was widespread, women were frequently excluded from obtaining digital guidance owing to family control of phones and suspicion ^[75]. Strategies for improving inclusion include: providing information in local languages and audio formats (to address literacy barriers), developing content around crops women grow, timing voice calls at convenient times, involving male family members in training to help them support women's access and explicitly targeting women in program design ^[76, 77]. For example, Grameen Foundation's Agripath initiative incorporates gender analysis by examining who makes choices on the farm and structuring training

appropriately. Overall, gender-sensitive extension entails addressing women's demands from the beginning (e.g., female extension agents, women-only group chats) and not as an afterthought ^[78].

Youth

Younger farmers are more likely to utilize digital instruments, appreciating their efficiency and ingenuity. Youth provide a "digital multiplier" function: as Grow Asia argues, young farmers are frequently the early adopters of new technology, share their triumphs on social media and affect their peers' perspectives ^[79]. Involving youngsters helps spread information more quickly and also builds the next generation of farmers. Effective initiatives empower kids via support for youth-led demonstration farms, incorporating agriculture into tech curriculum and even hiring young agripreneurs as extension partners ^[80]. But youth adoption has challenges too, like other farmers they require ROI evidence and access to funding. Policies may exploit youth as trainers and marketers of digital Ag instruments, contributing to sustainable growth of services ^[81].

Other Inclusion Considerations

Inclusiveness also means include minority linguistic groups, farmers with disabilities and the extremely poor. Low-tech media (SMS, radio) often better reach the poorest without cellphones ^[82]. Rural digital training has to be inclusive (e.g. visuals or voice for the illiterate, adaptable interfaces for the handicapped). Cultural relevance is important: extension material that disregards local customs or labour restrictions may not be successful ^[83]. A hybrid model of digital advice and community meetings or radio guarantees no group is left behind in many areas. Ultimately digital extension equality demands conscious design (to overcome the "digital divide"), not merely technology deployment ^[84].

Cost-Effectiveness and Business Models

- Digital extension often achieves high cost-effectiveness due to low incremental delivery costs. Studies estimate unit costs (per advisory message delivered) in the cents or low dollars for SMS and voice platforms. Economies of scale kick in once infrastructure is built: serving 10, 000 farmers costs only marginally more than serving 1, 000 ^[85]. For example, SMS advisories to millions in India and elsewhere have remarkably low per-farmer costs. By contrast, traditional extension worker visits require significant travel and labor costs ^[86].
- However, sustainable financing remains a challenge. Many pilots have been donor-funded and free for farmers. Long-term models include: public funding (governments subsidize national extension services via ICT), private sector (agribusinesses or telecoms view advisory as loss-leader or premium service) and social enterprise (users pay small fees, or services are bundled with input sales) ^[87]. Payment-for-services is sensitive for smallholders, many projects thus explore partial cost-recovery (e.g. charging agribusiness firms for bulk SMS campaigns, offering premium analytics to input dealers). Partnerships help: e.g. mobile network operators sometimes sponsor agrinfo SMS to gain customers ^[88].
- Impact evaluations often include benefit-cost ratios. One analysis of a mobile advisory program in Africa found benefit-cost ratios well above 1 (i.e. benefits double or triple costs). Another method calculates the willingness to pay by

farmers: in India, some farmers would pay up to 45% of their net profits for high-quality advisory^[89]. These findings indicate that if delivered value is high, digital extension can sustain itself economically. Still, upfront investment in platforms, data and capacity-building is needed and programs must plan for maintenance and updates (not just one-off interventions)^[90].

Scalability

- Digital tools are inherently scalable: software can be cloned at minimal cost and messages broadcast widely. High scalability has been demonstrated: national services reaching millions in India, Ghana, Kenya etc. But scaling beyond pilots requires careful attention to context. Crucial factors include government endorsement, local partner networks and user support systems. Technical scalability (server capacity, bandwidth) is solvable, but organizational scalability (training agents across regions, ensuring content relevance everywhere) is more complex^[91].
- Evidence shows successful scale-up often involves public-private partnerships. For instance, India's mKisan was a government initiative, whereas many African countries relied on private agtech startups with NGO support. Hybrid models where governments handle policy and oversight and private apps deliver the tech have promise. Digital platforms can also bridge national boundaries (e.g., FAO's global farmer helplines), but language and agronomic differences limit direct transfer. Thus, scalable solutions often require localization teams^[92].
- Replicability is helped by open standards: common data formats, open APIs and coordinated extension strategies. Where standards exist (like India's eNAM interoperable market system), scaling is easier. Where every project reinvents the wheel, growth stalls. Many experts advocate for integrated national agri-information systems, so that multiple services share a digital backbone. In sum, scalability is a technical strength of digital extension, but achieving it requires building institutional capacity, ensuring content diversity and securing sustainable funding^[93].

Policy Implications

Policymakers play a pivotal role in enabling digital extension. Key implications include:

- Investment in rural connection is critical to enabling the development of a base for the spread of mobile and internet infrastructure into remote areas. In addition, telecommunications coverage in rural areas may be expanded via joint ventures or subsidies^[94, 95].
- Governments may demonstrate their commitment to the promotion of digital literacy and skills training by integrating digital skills into agricultural training courses (for farmers and extension workers). Providing financial assistance for community information and communication technology centers and online educational initiatives may quicken adoption^[96, 97].
- We need to take out actions promoting inclusive design to incorporate women and young people in the national agri-extension plans. It could be worthwhile, for example, to educate female extension workers or to target services at the crops women farm. Any more material may have to be released, as needed by policy makers, in a variety of publicly accessible forms and in a number of languages spoken in the local community^[98].

- Standards for the use of agricultural data would be set to encourage the development of trust. Developing standards for the transmission of data across platforms and organizations may promote the interoperability of services. However, there are privacy regulations that restrict the use of data acquired from farmers^[99].
- Policies need to enable charitable groups, mobile carriers and agritech companies to work together. This is an example of a public-private cooperation in action. So, for example, governments may give incentives to the firms developing agricultural applications, in the form of subsidies or tax breaks and then utilize existing public extension networks to distribute information^[100].
- Integration with Traditional Extension: While digital services are not a panacea, they work best when paired with activities that are conducted at more traditional levels. Digital technology should not replace field staff in mixed extension systems but complement their role. Policymakers should adopt these kind of systems. The hybrid technique has both benefits. Face-to-face contact gives competent guidance and information and communication technology delivers vast knowledge^[101].
- Evaluation frameworks of government extension projects should incorporate measuring of digital service. Some examples of these KPIs are: reach, user happiness, total outcomes etc. This is because monitoring and evaluation are of considerable importance. With impact assessment institutionalized, authorities may more easily identify effective initiatives and scale up those procedures^[102].
- Financial support methods like as subsidies or credit facilities may allow smallholders to obtain cell phones or pay mobile rates. These strategies may assist to reduce the effect of cost barriers. And that's not to mention the state subsidies that may help speed up digital expansion, assuming sustainability models (such as subscription tiers, advertising) would develop over time^[103].
- Disaster preparedness is thus critical: the outbreak has brought out the relevance of digital extension in times of need. Thus, it is important for decision-makers to integrate information and communications technology (ICT) strategies in disaster response plans. For instance, in times of droughts or epidemics, the speedy spreading of SMS messages may be quite helpful^[104, 105].

Conclusion

Digital agricultural extension is changing how information is disseminated and new ideas are introduced to smallholder farmers. This large body of research has proven that mobile phones and internet platforms provide rapid and personalized information on crops, weather, markets and other associated issues, leading in large productivity and profitability increases. Interactivity and scalability are among the key features of digital extension. Millions of farmers may be reached at minimal cost and two-way contact (phone calls or online chat) makes it simpler to tailor advice to the individual requirements of farmers. The catalysts are young people and farmers who are good at technology and barriers related to gender and literacy need to be actively addressed. Effective programs combine digital and traditional approaches for local relevance and confidence. In many circumstances the cost efficiency is high but the long term financial viability of an organization depends on the business models and the regulatory backing it gets. In order to maximise effect, stakeholders need to concentrate on connection and training, offer inclusive content and build public-

private partnerships. Furthermore, academics and policy makers should work together to create common measures and share their expertise across sites. In times of shock, such as the pandemic, the delivery of information to farmers via digital extension has been demonstrated to greatly increase resilience and resilience. It would be good if digital extension could bridge the gaps that occur in extension in rural regions with low areas of population density. It is vital to highlight that technology is just one half of the formula for success, human factors (e.g., responsive and farmer-centered implementation) and supporting ecosystems are equally critical. In conclusion, digital extension services may play a major role in impacting smallholder agriculture, therefore improving productivity, incomes and food security. However, to achieve this potential in full, it is important to overcome hurdles that are social, infrastructural and economic in character. Continuous innovation based on scientific principles and inclusive design would be of enormous help in ensuring that the dividends of the digital revolution are available to every single farmer.

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