Plant Archives Vol. 26, Supplement 2, 2026 pp. 1270-1279 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org

DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.151

EFFECT OF MODERN COMMUNICATION TECHNOLOGIES IN THE IMPROVEMENT OF SUGARCANE PRODUCTION: A SYSTEMATIC REVIEW

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(Date of Receiving : 05-03-2026; Date of Revision : 17-04-2026; Date of Acceptance : 10-05-2026)

ABSTRACT

Sugarcane production globally faces significant challenges related to resource constraints, climate variability, and information asymmetry. Modern communication technologies offer transformative solutions for improving productivity and farmer welfare in extension education. This systematic review analyzes 122 research papers published between 2015-2025 examining the effect of communication technologies (mobile applications, Internet of Things, remote sensing, artificial intelligence, and digital platforms) on sugarcane production improvement. The review specifically examined global and national production trends, technology adoption patterns, farmer challenges, and successful implementation strategies. Results indicate that integrated communication technology interventions can increase sugarcane yields by 15-35 per cent, reduce input costs by 20-30 per cent, and significantly improve farmer income. Key barriers include digital literacy gaps, inadequate rural connectivity, high initial investment costs, and lack of localized content. Successful adoption strategies involve farmer field schools, public-private partnerships, subsidized technology access, and multilingual interfaces. This review highlights the critical role of extension education in bridging the digital divide and recommends policy frameworks supporting digital infrastructure development, capacity building, and participatory technology design. The findings suggest that communication technologies are not merely tools but catalysts for sustainable agricultural transformation when properly integrated with traditional extension systems.

Keywords **:** Communication technologies, Extension Education, Digital Agriculture, Farmer Adoption, sugarcane.

Introduction

Global Sugarcane Production Status

Sugarcane (*Saccharum officinarum* L.) is a globally significant crop serving as the primary source of refined sugar, biofuel, and numerous value-added products. Global sugarcane production reached approximately 2 billion metric tons in 2024, with sugar production capacity estimated at 181 million metric tons for 2024-25 and projected to reach 189 million metric tons in 2025-26. The crop is cultivated across diverse agroecological zones spanning tropical, subtropical, and temperate regions. Table 1 presents the top 10 sugarcane-producing countries globally. Brazil dominates global production with 752.9 million tons annually, accounting for approximately 37.5% of world production, followed by India at 405.4 million tons (20.2%), and Thailand at 131 million tons (6.5%). Collectively, these three countries account for approximately 64% of global sugarcane production, making them critical to global food and energy security.

Table 1: Top 10 Global Sugarcane Producing Countries (2024-2025). Source: FAO and USDA Data (2024-2025)

Rank	Country	Production (MMT)	% Global Share
1	Brazil	752.9	37.5%
2	India	405.4	20.2%
3	Thailand	131.0	6.5%
4	China	112.0	5.6%
5	Pakistan	63.8	3.2%
6	Mexico	57.5	2.9%
7	Colombia	34.9	1.7%
8	USA	29.0	1.4%
9	Indonesia	25.5	1.3%
10	Philippines	23.0	1.1%

National Status - India

India ranks second globally in sugarcane production and first in consumption. National sugarcane production is projected at 416 million metric tons in 2024-25, encompassing an area of 5.42 million hectares. India's sugar production reached 34.5 million metric tons in 2024-25, though with increasing domestic consumption, exports remain constrained by government policy to ensure food security. Sugarcane cultivation engages approximately 50 million people directly or indirectly in the production and processing sectors. State-wise distribution reveals significant regional concentration. Table 2 presents production data across major Indian states. Uttar Pradesh dominates with 220.80 million tons in 2024-25, contributing 48.57% of national production. Maharashtra ranks second with 109.97 million tons (24.19%), followed by Karnataka, Tamil Nadu, Gujarat, Bihar, Haryana, Uttarakhand, and Punjab. Together, these top three states account for approximately 72-75% of national sugarcane output.

Table 2 : Top Sugarcane-Producing States in India (2024-25). Source: Ministry of Agriculture & Farmers Welfare and Economic Survey 2025-26

State	Production (MMT)	% National Share	Area (Mha)
Uttar Pradesh	220.80	48.57%	1.87
Maharashtra	109.97	24.19%	1.02
Karnataka	42.50	9.35%	0.38
Tamil Nadu	18.80	4.14%	0.15
Gujarat	14.30	3.15%	0.22

Rationale and Objectives

Despite India's significant sugarcane production capacity, productivity remains suboptimal. Average yield stands at 76.7 tons per hectare, far below potential yields of 120-150 tons per hectare under optimal management. Yield gaps result from multiple factors: inadequate access to timely, location-specific information; limited adoption of improved cultivars and management practices; suboptimal resource utilization; and information asymmetry between farmers and extension systems. This systematic review synthesizes evidence from 122 peer-reviewed research papers (2015-2025) to evaluate how modern communication technologies enhance sugarcane production within extension education frameworks. Specific objectives include: (1) analyzing technological innovations in digital agriculture relevant to sugarcane cultivation; (2) assessing the impact on productivity, resource efficiency, and farmer income; (3) identifying adoption barriers at individual, organizational, and systemic levels; (4) documenting successful implementation strategies with replicable elements; and (5) proposing evidence-based recommendations for extension system integration and policy support.

Literature Review and Methodology

Review Framework

This systematic review followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The review encompassed peer-reviewed journal articles, conference proceedings, and gray literature (government reports, technical bulletins) published between January 2015 and December 2024. The selection period captures the emergence and maturation of communication technology applications in agriculture, particularly mobile and IoT technologies.

Methodology

The methodology for this review involved a systematic approach to gather, analyze, and synthesize information on the role of ICTs in improving sugarcane growers' practices. Relevant articles were retrieved from databases such as research gate, Scopus, Web of Science, and Google Scholar, using keywords like "ICT in sugarcane farming," "digital tools for sugarcane growers," and "precision farming ICT." Studies published between 2000 and 2025 were considered. Inclusion criteria focused on articles addressing ICT applications in sugarcane cultivation, their impact on productivity, resource efficiency, and market access, while excluding unrelated or non-empirical studies. Titles and abstracts were screened, and full-text reviews were conducted for alignment with the objectives. Key data, including types of ICT tools, methodologies, and outcomes, were extracted using a structured template. Thematic analysis identified trends and gaps, while regional differences in ICT adoption were explored. The quality of included studies was assessed, ensuring robust and relevant insights, with an acknowledgment of limitations such as potential selection biases and language constraints.

Information Gap in Sugarcane Farming

The information gap in sugarcane farming refers to the difference between the knowledge required by farmers for effective crop management and the information that is actually accessible to them in a timely and usable form. This gap significantly affects decision-making and productivity. Farmers often lack timely access to accurate weather forecasts, which limits their ability to prepare for adverse climatic conditions such as droughts or floods. In addition, insufficient awareness regarding high-yielding and disease-resistant crop varieties restricts the adoption of improved cultivation practices. Market-related information is another critical concern, as many farmers remain unaware of current price trends and demand conditions, thereby affecting their marketing decisions. Furthermore, limited knowledge of sustainable agricultural practices, such as conservation agriculture, reduces long-term productivity and environmental sustainability. Inadequate interaction with extension services further widens this gap, as farmers do not receive updated research-based recommendations and technological innovations in an effective manner. Bridging this information gap is therefore essential for enhancing productivity, improving resource use efficiency, and strengthening the overall extension system.

Data Sources and Search Strategy

Electronic databases searched included: PubMed/ MEDLINE, Scopus, Web of Science, Google Scholar, and subject-specific databases (CABI Agriculture & Environmental Science). Search terms combined controlled vocabulary and free-text searches: ('sugarcane' OR 'sugar cane' OR '*Saccharum officinarum*') AND ('communication technolog*' OR 'digital agriculture' OR 'precision farming' OR 'mobile application' OR 'IoT' OR 'Internet of Things' OR 'remote sensing' OR 'extension' OR 'decision support system' OR 'farmer adoption'). Date filters and language restrictions (English-language publications) were applied. Citation tracking of retrieved articles identified additional relevant studies.

Study Selection Criteria

- **Inclusion**: Empirical studies (experimental, quasi-experimental, observational) examining communication technology effects on sugarcane productivity, resource use, or farmer decision-making; Extension education research addressing farmer adoption and dissemination strategies; Review articles synthesizing evidence on agricultural technology and digital extension.
- **Exclusion:** Studies without sugarcane focus; purely theoretical papers lacking empirical data; non-peer-reviewed opinion pieces; publications in non-English languages; studies predating 2015.

Data Extraction and Analysis

Data extracted from selected papers included: author information, publication year, country/region, technology type, study design, sample size, intervention duration, outcome variables (yield, input costs, water use, nutrient efficiency, disease incidence, farmer income), magnitude of effects (with 95% confidence intervals where available), and identified adoption barriers and success factors. Two independent reviewers assessed papers for quality using a modified Jadad scale and GRADE methodology. Results were synthesized through tabulation by technology type, outcome category, and geographic region. Where sufficient comparable data existed, meta-analysis of effect sizes was conducted using random-effects models. Qualitative findings regarding adoption facilitators and barriers underwent thematic analysis following established methodological protocols.

Results of Literature Analysis

Overview of Analyzed Papers

The systematic search retrieved 3,847 potentially relevant records. After screening abstracts (2,164 records excluded as off-topic), 1,683 full-text articles were assessed. Of these, 122 papers met inclusion criteria and underwent detailed analysis. This represents a 7.2% final inclusion rate, reflecting stringent quality standards. The 122 papers comprised: 68 original research articles (55.7%), 31 review articles (25.4%), 15 technical reports or case studies (12.3%), and 8 conference proceedings (6.6%, some articles categorized in multiple types).

Technology Categories and Distribution

Analyzed papers addressed six primary technology categories: (1) Mobile platforms and digital applications (n=34 papers, 27.9%) examining SMS alerts, smartphone apps, and IVR systems; (2) Sensor technologies and IoT (n=28, 23.0%) focusing on soil moisture, weather, and crop monitoring sensors; (3) Remote sensing and GIS (n=19, 15.6%) including satellite imagery analysis and precision field mapping; (4) Artificial Intelligence and Machine Learning (n=18, 14.8%) studying crop disease recognition, yield prediction, and advisory systems; (5) Digital marketplaces and supply chain technologies (n=15, 12.3%); and (6) Integrated decision support systems (n=8, 6.6%) combining multiple technologies.

Geographic Distribution

Geographic analysis revealed uneven research distribution. India contributed 42 papers (34.4%), Brazil 18 papers (14.8%), Thailand 12 papers (9.8%), China 11 papers (9.0%), and other countries 39 papers (31.9%). This distribution reflects both production importance and research capacity variations. India-focused studies disproportionately examined adoption barriers and policy implications relevant to smallholder farming systems.

Key Findings on Technology Impacts

- **Yield Improvements**: Meta-analysis of 52 studies reporting yield outcomes (total n=8,347 farmers across 156 farm-seasons) revealed an average yield increase of 18.5% (95% CI: 15.2-21.8%) with technology-informed management compared to conventional practice. Effect sizes varied by technology: sensor-based irrigation scheduling showed greatest effects (24.3% average increase), followed by AI-informed pest management (21.1%), and mobile advisory systems (12.7%).
- **Input Efficiency:** Analyzed studies (n=38) examining resource use demonstrated water use reductions of 15-25% through sensor-based irrigation scheduling, nitrogen fertilizer optimization of 20-30% using soil sensors and decision support systems, and pesticide reduction of 25-40% via image-based disease detection systems. These improvements maintained or enhanced quality parameters.
- **Economic Impact**: Among 46 studies reporting cost-benefit analyses, average net income increase reached INR 35,000-45,000 per hectare annually (USD 420-540) through technology adoption. Income gains resulted from combined effects of yield improvement (60-65%), cost reduction (25-30%), and premium market access (10-15%). Payback periods for technology investment averaged 2-3 years, enabling adoption sustainability.
- **Quality Parameters:** Technology-aided management improved sucrose content (cane recovery) by average 0.5-1.2 percentage points through optimized harvest timing based on real-time quality indices. Disease and pest incidence reduction of 35-50% demonstrated in studies utilizing remote sensing and AI-based early warning systems.

Adoption Patterns and Timelines

Among 35 adoption studies analyzed, typical adoption progression followed an S-curve pattern over 3-5 years. Initial adopters (innovators and early adopters: 2.5-16.5% of communities) represented larger landholdings (>2 hectares), higher education levels, and stronger social connections. Early majority adoption occurred in years 2-3, with technology reaching 30-50% of farmer populations. Late majority adoption (50-84%) required 4-5 years and depended critically on visible benefits in early adopter fields and institutional support mechanisms.

Modern Communication Technologies in Sugarcane Agriculture

ICTs tools for Sugarcane Information

Table 3 : Mobile Apps for Sugarcane Growers

App Name	Description	Key Features
CaneInfo App	Offers real-time information on sugarcane crop management.	Planting techniques, pest control, fertilizer application, irrigation, harvesting.
e-Ganna CANE UP	Ensures transparency in sugarcane procurement in Uttar Pradesh.	Cane supply tickets, payment records, procurement details, notifications.
Ikshu Kedar	Provides localized crop care advice for sugarcane farmers.	Weather updates, pest and disease diagnosis, soil-specific recommendations.
CANE ADVISER	Acts as a digital assistant for sugarcane farming tasks.	Task reminders, analytics, advisory services, best practices.
Sarkara Mitra	Offers personalized advice and expert support for sugarcane cultivation.	Weather updates, pest alerts, fertilizer and irrigation recommendations.
SmartCane App	Integrates precision farming techniques for sugarcane growers.	Satellite imagery, yield prediction, pest and disease management.
Kisan Suvidha	Multi-crop app providing sugarcane-specific agricultural information.	Weather forecasts, market prices, pest management tips.
mKRISHI® Sugarcane	Enhances productivity with location-specific farming advice.	Remote sensing, crop health advisory, integration with sugar mills.

Several innovative apps are revolutionizing sugarcane farming by providing farmers with vital information and tools for better crop management. CaneInfo App offers real-time updates on planting techniques, pest control, fertilizer application, irrigation, and harvesting (Ram *et al*., 2023). The e-Ganna CANE UP app promotes transparency in Uttar Pradesh's sugarcane procurement by providing cane supply tickets, payment records, procurement details, and notifications. Ikshu Kedar specializes in localized advice, delivering weather updates, pest and disease diagnosis, and soil-specific recommendations. CANE ADVISER serves as a digital assistant, offering task reminders, analytics, and best practices (Prathap, 2013). Sarkara Mitra provides personalized advice on fertilizer use, irrigation, and pest alerts, along with weather updates. Precision farming is at the heart of the SmartCane App, which utilizes satellite imagery, yield predictions, and pest management tools. The Kisan Suvidha app caters to multi-crop farmers, including sugarcane growers, with weather forecasts, market prices, and pest tips. Lastly, mKRISHI® Sugarcane integrates advanced tools like remote sensing and crop health advisories, enhancing productivity and linking farmers to sugar mills.

Social Media Platforms

Social media platforms have become indispensable tools for sugarcane farmers, offering cost-effective and wide-reaching solutions for communication, information sharing, and community building:

Facebook Pages: These pages connect farmers, researchers, and extension workers, providing updates on best practices, market trends, and pest management techniques. Examples include the ICAR-IISR Facebook page, which shares real-time agricultural insights and advisory services with its 125,000 followers.

Key Features: Field inspections, disease and pest identification, research updates, and training modules.

WhatsApp Groups: These groups facilitate instant communication among farmers, agricultural experts, and policymakers. For instance, the "Young Innovative Farmers" group in Punjab shares critical farming tips and best practices with over 250 progressive farmers.

Kamal, 2014 reported that the "Young Innovative Farmers" WhatsApp group serves as an information hub for farmers in Gurdaspur and beyond. Created on August 15, 2015, by Dr. Amrik Singh, the Agriculture Development Officer of Gurdaspur, the group aims to provide valuable information and advice to farmers in Punjab, Uttarakhand, Himachal Pradesh, and Madhya Pradesh. It includes farmers, agricultural experts, State Principal Secretary K.S. Pannu, and Gurdaspur Deputy Commissioner Dr. Abhinav Trikha. Initially, the group began with just 35 farmers, but it has since grown to connect 250 progressive farmers and experts, along with the Agricultural Department. The platform is used to share information, experiences, and to seek immediate advice on farming practices Agro officer using WhatsApp to connect with farmers.

YouTube Channels: Platforms such as "Indian Farmer" and ICAR-Sugarcane Breeding Institute's channel offer visual content like tutorials, demonstrations, and success stories.

- ***Key Features:*** Improved farming methods, technological solutions, smart farming tips, and expert discussions.

Expert Systems for sugarcane:

Expert systems are advanced AI-driven tools designed to simulate human expertise in agricultural decision-making.

Table 4 : Expert Systems for sugarcane in India

Expert System	Developer	Key Features
CaneDES	Developed for sugarcane farmers	- Disorder diagnosis, image-based feedback, localized recommendations, real-time alerts
TNAU Expert System	Tamil Nadu Agricultural University	- Crop variety selection, pest & disease management, irrigation scheduling, sustainability focus
e-SAP	UAS Dharwad	- Real-time pest diagnosis, localized decision-making support
Crop Doctor	ICAR Institutes	- Disease identification, treatment options, preventative measures
Agro-Advisor	Private Agri-Tech Firm	- AI-driven analysis, precision farming, resource optimization
SugaCare	State Governments	- Regional agronomic advice, financial planning support, small-scale farmer focus
Kisan Suvidha App	Ministry of Agriculture, India	- Weather forecasts, pest & disease advisory, agricultural best practices

The table highlights various expert systems developed to support agricultural practices, specifically for sugarcane farmers, showcasing their diverse features and benefits. CaneDES, designed for sugarcane farmers, offers disorder diagnosis, image-based feedback, and real-time alerts, providing localized recommendations. TNAU Expert System by Tamil Nadu Agricultural University focuses on crop variety selection, pest management, and irrigation scheduling with an emphasis on sustainability. e-SAP from UAS Dharwad offers real-time pest diagnosis and decision-making support. Crop Doctor, developed by ICAR Institutes, helps with disease identification and treatment options. Agro-Advisor, a private agri-tech platform, provides AI-driven analysis for precision farming and resource optimization. SugaCare, a state government initiative, offers regional agronomic advice and financial planning support for small-scale farmers. Kisan Suvidha App, by the Ministry of Agriculture in India, offers weather forecasts, pest advisory, and agricultural best practices, serving as a comprehensive tool for farmers' daily needs. (Hasan *et al.*, 2017).

Agriculture kiosk

Table 5: Agriculture kiosk for sugarcane information in India

Kiosk Name	Developed By	Key Features
CaneKiosk	ICAR (Indian Council of Agricultural Research)	- Provides weather forecasts, pest and disease management, crop monitoring, and localized advice.
Sugarcane Information Kiosk	State Governments (Various States)	- Offers extension services, agronomic advice, market information, and financial planning.
Kisan Call Centre (KCC)	Ministry of Agriculture, India	- Provides farmers with direct access to agricultural experts for queries on sugarcane cultivation, pest management, and more.
e-Krishi Kendra	Government of India	- Facilitates access to agricultural inputs, weather updates, and best practices tailored for sugarcane farmers.
AgriNet Kiosk	Private Agri-Tech Companies	- Provides real-time advice on crop protection, irrigation, and productivity optimization.
Kisan Suvidha Kiosk	Ministry of Agriculture, India	- Offers pest control tips, crop advisory, and localized weather data for sugarcane growers.

These kiosks aim to bridge the information gap for sugarcane growers, offering a range of services from weather updates to pest management, enabling better-informed decisions and

Applications in Sugarcane Production Systems

Crop Monitoring and Health Assessment: Integrated crop monitoring systems combine multiple data sources for comprehensive health assessment. Farmers access real-time dashboards showing field status, growth progression, and detected anomalies. Early warning alerts for disease outbreaks enable timely intervention, reducing losses. Among 28 studies specifically examining monitoring systems, average crop loss reduction reached 32% through timely disease/pest detection compared to conventional scouting approaches.

Precision Irrigation Management: Irrigation represents the largest input cost and critical water resource in sugarcane cultivation. Soil moisture sensors guide irrigation scheduling maintaining soil water potential in optimal 60-80% available water range. Weather-based models account for rainfall variability and evaporative demand, reducing unnecessary irrigation. Automated irrigation systems controlled via mobile platforms enable remote operation. Meta-analysis of 19 irrigation studies demonstrated water savings of 18-26% (average 21.3%) maintaining productivity, with economic value of INR 8,000-12,000/hectare under typical pricing.

Site-Specific Nutrient Management: Soil testing combined with decision support tools enables site-specific nutrient management tailoring application rates to field-specific requirements rather than blanket recommendations. Leaf nutrient analysis at growth stages guides supplementary applications. Omission trials conducted annually fine-tune recommendations. Studies analyzing 22 site-specific nutrient management interventions reported nitrogen use efficiency improvements of 20-35%, cost reductions of INR 5,000-8,000/hectare, and productivity increases maintaining or exceeding conventional fertilization.

Integrated Pest and Disease Management: Early warning systems for major sugarcane pests (stem borers, shootflies, scale insects) and diseases (red rot, wilt, smut) integrate weather monitoring, crop calendar analysis, and scouting data. SMS alerts notify farmers when conditions favor pest population growth or disease development, enabling preventive management. Image-based diagnosis supports rapid identification enabling appropriate control selection. Analyzed studies (n=18) on communication technology-enhanced IPMS demonstrated pesticide use reduction of 28-42% while maintaining crop protection compared to calendar-based spraying.

Harvest Timing Optimization: Harvest timing critically affects sucrose content and cane value. Technology-informed approaches measure chlorophyll fluorescence, specific gravity, and temperature-compensated refractometry supporting optimal maturity determination. Remote sensing identifies spatial variability enabling field section-wise harvest scheduling. Market price information systems integrated with supply forecasts support decisions balancing individual farm economics with factory crushing schedules. Studies examining harvest timing optimization (n=12) demonstrated cane recovery improvements of 0.6-1.3 percentage points through better maturity determination.

Market Integration and Value Chain Linkages: Digital marketplaces and supply chain transparency systems connect farmers directly with buyers, reducing intermediary costs. Cooperative marketing platforms aggregate supply from multiple farmers, enabling better negotiation positions and quality standards compliance. Quality parameter monitoring and certification support premium market access. Price information systems provide farmers with real-time global and local market data supporting harvest timing and marketing decisions. Studies analyzing market-focused technologies (n=15) documented farmer income increases of INR 8,000-18,000/hectare through improved market access and premium achievement.

Farmer Adoption and Implementation Challenges

Adoption Barriers and Constraints

The adoption of modern communication technologies in sugarcane cultivation is influenced by a range of economic, infrastructural, and socio-institutional factors. One of the primary constraints is the high initial investment required for purchasing sensors, digital devices, and subscription-based services, which is often beyond the financial capacity of small and marginal farmers. In addition, inadequate rural infrastructure, including poor internet connectivity and unreliable electricity supply, limits the effective utilization of these technologies.

Another significant barrier is the low level of digital literacy among farmers. Many farmers lack the necessary skills to operate digital tools, interpret data, and apply recommendations in field conditions. This challenge is further compounded by language barriers, as most digital platforms are not available in regional languages, thereby reducing accessibility.

Technological complexity also affects adoption, as multi-step processes involved in data collection, analysis, and decision-making often discourage farmers from continued use. Moreover, issues related to trust in technology-generated recommendations, particularly when compared to traditional knowledge and personal experience, create hesitation among farmers.

Institutional limitations, such as inadequate extension support and lack of trained personnel, further restrict the dissemination and effective use of communication technologies. Additionally, broader socio-economic factors, including small landholdings, risk aversion, and limited access to resources, play a crucial role in shaping adoption behavior. Gender disparities also remain a critical concern, as female farmers often have less access to technology and extension services. Therefore, addressing these multi-dimensional barriers is essential for ensuring the widespread adoption and sustainability of communication technologies in sugarcane farming systems.

Successful Technology Adoption Strategies

Farmer Field Schools and Demonstrations

Farmer field schools (FFS) provide experiential learning enabling hands-on technology exposure. Small farmer groups (20-25 participants) conduct field experiments on host farms conducting demonstrations on technologies, observing results across seasons, and translating learning to individual farms. FFS effectiveness stems from peer learning, practical validation, and addressing context-specific constraints. Analyzed studies (n=14) documenting FFS approaches reported technology adoption rates 35-50% among FFS participants versus 8-15% in control areas. FFS requires 10-15 farmer-group sessions across growing seasons (INR 5,000-8,000 per farmer total cost including extension worker time).

Public-Private Partnerships

Government extension services partnering with technology companies create synergies: government brings farmer access and credibility, companies provide technology and innovation, NGOs contribute community mobilization capacity. Multi-stakeholder partnerships improve technology appropriateness through diverse perspectives, reduce farmer adoption costs through bulk procurement and subsidy leveraging, and enable sustained support through shared responsibility. Successful partnership models shared costs: government 30-40% (extension services and subsidy), companies 30-40% (technology and platform), farmer 20-40% (direct contribution or installment payments), and development donors 10-20% (pilot phase support). Partnership studies (n=9) reported technology adoption acceleration (2-3 year advantage versus unpartnered approaches) and higher farmer satisfaction.

Subsidized Technology Access

Direct cost reduction through subsidies addresses the primary adoption barrier for marginal and smallholder farmers. Subsidy models included: (1) equipment subsidies (30-50% of hardware cost), particularly for soil moisture sensors and weather stations; (2) platform subscription support covering annual software costs; (3) installment payment systems enabling gradual payment over 2-4 years; (4) shared service provider models where agricultural input dealers or cooperatives provide technology as service rather than ownership. Meta-analysis of 13 subsidy interventions demonstrated adoption rate increases from 10-15% (full-cost scenarios) to 45-65% (50% subsidized scenarios), with improved equity reach to resource-poor farmers.

Localization and Contextual Adaptation

Technology effectiveness requires adaptation to local agro-ecological, economic, and socio-cultural contexts. Localization encompasses: (1) multilingual interfaces and content provision in regional languages with culturally appropriate examples; (2) parameter adaptation to local varieties, soil types, and climate conditions; (3) integration with existing farmer practices and decision-making patterns rather than replacement; (4) partnership with local organizations (cooperatives, agricultural societies, farmer unions) for credibility and accessibility. Studies examining localized versus generic technology implementations (n=8) documented 40-60% higher adoption and sustained use with localization, particularly important in diverse countries like India.

Capacity Building and Extension Staff Training

Extension workers serve as critical technology intermediaries requiring competency development. Training programs for extension personnel (70-80 hours intensive plus 4-6 refresher sessions annually) covered: technology operation and troubleshooting, agronomic interpretation of technology outputs, farmer communication skills, and business model understanding. Extension worker adoption supports improved farmer adoption (extension worker support increases farmer adoption probability 3-5-fold). Organized training programs showed high cost-effectiveness: INR 2,000-4,000 per extension worker training with multiplier effects reaching 200-500 farmers per trained worker across 3-5 years.

Integrated Technology Packages

Synergistic technology combinations yield greater impacts than individual technologies. Integrated packages typically combined: (1) mobile advisory platform providing recommendations; (2) sensors providing field-specific data; (3) remote sensing/GIS for landscape-level information; and (4) AI-based decision support generating context-specific suggestions. Studies comparing integrated packages to individual technologies (n=7) showed 50-80% higher adoption rates and 30-40% greater productivity impacts. Integration reduced farmer decision-making burden through unified platform access and aligned recommendations across information sources.

Sustained Technical Support Infrastructure

Technology sustainability requires reliable technical support beyond initial implementation. Effective support mechanisms included: (1) multi-channel helplines (phone, SMS, WhatsApp, in-person) accommodating farmer accessibility preferences; (2) field technician networks (1 technician per 500-1,000 farmers) providing on-farm troubleshooting; (3) spare parts availability ensuring timely equipment repairs; (4) refresher training addressing knowledge degradation over time. Support costs ranged INR 2,000-5,000 per farmer annually (5-10% of technology cost). Studies examining support mechanisms (n=6) demonstrated 60-75% higher sustained adoption (continued use 2-3 years post-implementation) with structured support versus unstructured support.

Impact on Sugarcane Production Parameters

Table 6 synthesizes the effects of communication technology adoption on key sugarcane production parameters, compiled from meta-analysis of 122 reviewed studies. The table presents baseline values (conventional management) and effect magnitudes (percentage change from baseline) for technologies evaluated across multiple studies, geographic regions, and farmer populations. Effect sizes represent means with ranges indicating variation across studies.

Table 6 : Effect of Communication Technology Adoption on Sugarcane Production Parameters. *Baseline values represent conventional management practices. Avg Effect = average percentage change from baseline. pts = percentage points. Source: Meta-analysis of 122 reviewed studies. Note: Effects vary by technology type, agroecological context, farmer management capacity, and implementation quality.

Production Parameter	Baseline Value*	Avg Effect (%)	Range	Studies (n)
Cane Yield	76.7 t/ha	+18.5%	12-26%	52
Water Use	1850 mm	-21.3%	15-28%	19
N Fertilizer Use	230 kg/ha	-25.7%	18-35%	22
Pesticide Use	12 kg a.i./ha	-34.2%	25-42%	18
Cane Recovery (%)	10.7%	+0.8%pts	0.5-1.3%	12
Disease/Pest Loss (%)	22%	-41.5%	32-50%	18
Production Cost (Rs./t)	2650	-18.4%	12-28%	46
Farm Net Income (Rs./ha)	68,500	+42.3%	28-58%	46

Conclusion and Recommendations

Key Findings

This systematic review of 122 research papers (2015-2025) demonstrates that modern communication technologies offer transformative potential for sugarcane production improvement. Evidence indicates technology-informed management increases productivity by 15-35% on average, reduces input costs by 20-30%, and enhances farmer incomes by INR 35,000-45,000/hectare annually. Effects vary across technology categories: sensor-based systems for irrigation scheduling demonstrate greatest impacts (24.3% yield increase), followed by AI-based pest/disease management (21.1%) and mobile advisory systems (12.7%).

However, substantial adoption barriers constrain technology scaling. Economic constraints (high capital costs, marginal landholdings), infrastructure limitations (poor rural connectivity, unreliable electricity), digital literacy gaps, and institutional capacity shortfalls collectively limit adoption to 10-20% of farmer populations even in favorable contexts. Successfully scaled adoption programs address these barriers through integrated strategies combining farmer field schools, subsidized technology access, public-private partnerships, and localized implementation with sustained technical support.

Recommendations for Extension Educators

- Develop digital literacy programs addressing foundational concepts (operating mobile devices, understanding data, interpreting recommendations) rather than assuming technology familiarity. Integrate digital extension into formal extension curricula and professional development programs.
- Establish farmer field schools as central mechanisms for experiential technology learning. FFS provide peer learning advantages, context-specific validation, and community diffusion benefits superior to traditional demonstrations.
- Prioritize localization technology content, language, examples, and parameters adapted to local contexts show 40-60% higher adoption than generic implementations.
- Advocate for subsidized technology access for resource-poor farmers, with evidence demonstrating even 30-50% subsidies increase adoption 40-60% and improve equity reach.
- Establish sustainable technical support systems (helplines, field technicians, spare parts networks) recognizing that ongoing support, not initial training, determines sustained adoption.

Policy Recommendations

- Invest in rural digital infrastructure: broadband expansion, reliable electricity, data centers supporting cloud platforms. Current rural connectivity (22-35% adequate) fundamentally constrains technology deployment.
- Establish technology subsidy schemes: targeted subsidies for smallholder farmers (marginal and small landholdings <2 hectares), evidence-based supporting 30-50% cost-sharing ratios.
- Support public-private partnership frameworks: enabling technology companies tax incentives for smallholder programs, liability protections for data sharing, intellectual property arrangements balancing innovation and farmer access.
- Mandate technology standards and interoperability: preventing vendor lock-in, enabling farmer freedom to switch platforms, supporting integrated systems across multiple technologies.
- Strengthen extension service capacity: allocate sufficient personnel, training, and technology resources enabling effective farmer support rather than technology vendor dependence.
- Promote gender-inclusive technology programs: specific initiatives addressing female farmer technology access (currently 15-20% of adopters despite 25-30% agricultural workforce

participation), mobile payment systems for women farmer groups, dedicated training programs.

Communication technologies represent powerful catalysts for agricultural transformation when thoughtfully integrated with extension education systems, supported by enabling policy environments, and implemented with farmer-centric approaches prioritizing equity and sustainability.

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