

Article

Field-Ready HCI: A Conceptual Model of Mobile Application Use in Agriculture for Low-Resource and Smallholder Contexts

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Featured Application

Our proposed “field-ready HCI” model offers a framework for designing and evaluating mobile agricultural applications for smallholder and low-resource contexts. It guides choices about local-language and low-literacy interfaces, offline operation, explainable advice, trust signals, and integration with extension and farmer networks.

Abstract

Mobile applications are increasingly promoted as instruments for improving agricultural information access, advisory delivery, market participation, and decision support, particularly for smallholder farmers in developing nations. Research, however, has been dominated by general technology-acceptance and diffusion constructs, while the design-sensitive and infrastructural mechanisms studied in human–computer interaction (HCI) have received comparatively little attention. In this paper we develop a parsimonious HCI model of mobile application use in agriculture. Drawing on the technology acceptance model, the unified theory of acceptance and use of technology, diffusion of innovations, socio-technical systems theory, and human–computer interaction for development (HCI4D), the model proposes that agricultural application use is driven by five antecedent domains: perceived agronomic value, inclusive usability and accessibility, contextual and cultural fit, trust and transparency, and social and institutional embeddedness. Each plays a distinct role across three use stages: adoption intention, sustained use, and decision impact. Contextual constraints (infrastructure and farmer characteristics) moderate these relationships. We develop six testable propositions from the model. The model is conceptual: it is offered as a framework for empirical testing rather than as a validated account of farmer behavior. The paper contributes an HCI-sensitive specification of mobile application use under agricultural field conditions: a “field-ready” conception of mobile HCI.

Keywords: human–computer interaction; HCI4D; mobile applications; agriculture; technology adoption; smallholder farmers; usability; trust; participatory design; farmer empowerment



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1. Introduction

Agriculture is an information-intensive and uncertainty-laden endeavor. Farmers make repeated, time-sensitive decisions under conditions of weather variability, pest and disease pressure, price volatility, input constraints, limited advisory access, and unequal market power. For more than a decade, mobile technologies have been proposed as a

means of easing these burdens: lowering the search and transaction costs that disadvantage smallholders (here, farmers who cultivate small landholdings, commonly under two hectares, and rely largely on family labor and limited capital), thereby extending agricultural advice beyond the reach of conventional systems and linking farmers to markets, finance, and weather information [1–4]. The rapid diffusion of mobile telephony across sub-Saharan Africa has, in particular, positioned mobile applications as a putative solution to long-standing agricultural challenges [5,6].

Mobile applications in agriculture are not, however, merely technical instruments. They are socio-technical interfaces that mediate relationships among farmers, markets, weather systems, financial providers, input suppliers, government agencies, and increasingly, artificial intelligence (AI) and sensor-enabled platforms. A weather alert, a fertilizer recommendation, a market price, or a pest diagnosis reaches the farmer only through an interface that must be perceived, understood, trusted, and acted upon, often under conditions far removed from the office or domestic settings for which mainstream mobile software is designed. We propose that the interaction between a farmer and an application is therefore an HCI problem as much as an adoption problem.

Consider a smallholder who receives an image-based pest diagnosis on a shared, low-specification phone while standing in a field in bright sunlight, with patchy network coverage and a data balance they are reluctant to spend. Whether they act on the diagnosis depends on far more than the accuracy of the underlying model. It depends on whether the interface is legible and whether the recommendation is in their language and idioms, whether they can understand why the advice was given, whether they trust the organization behind the application, and whether the recommended solution is locally available and affordable. Each of these is a socio-technical consideration that conventional adoption variables capture only obliquely.

Despite this, much of the agriculture-application literature continues to explain uptake through variables derived from the technology acceptance model (TAM), the unified theory of acceptance and use of technology (UTAUT), and diffusion of innovations. These frameworks have generated insight. For example, reviews of mobile agricultural service applications in sub-Saharan Africa consistently identify perceived usefulness as a leading determinant of adoption [7]. However, they treat the interface itself, and the conditions of its use, largely as a black box. Concerns that are central to HCI, such as accessibility, usability, explainability, trust, values, culture, and language, remain relatively underexplored in agricultural settings [8,9].

These frameworks differ, moreover, in where they fall silent, and naming those silences motivates the integration we develop. TAM, organized around perceived usefulness and ease of use, has difficulty representing the concrete interaction barriers that arise with low literacy, multilingual use, shared or low-specification devices, and outdoor field operation; “ease of use” is treated as a global perception rather than as a property of a particular interface encountered under particular conditions. Diffusion of innovations explains spread through relative advantage, compatibility, and social influence, but says comparatively little about the transparency of AI-generated recommendations, the data-ethics expectations of users, or the trust mechanisms through which farmers decide whether to believe automated advice. HCI4D attends closely to low-resource interaction, yet its core concerns, such as voice interfaces, iconographic navigation, and low-literacy design, have been only loosely connected to the agricultural realities of decision risk, seasonal production cycles, and dependence on extension systems. UTAUT adds facilitating conditions and social influence but does not, on its own, account for field-based interface usability. No single framework, in short, spans the interaction-level and infrastructure-level mechanisms

that decide whether an agricultural application is actually used; closing that gap is the purpose of our integration.

The central argument of our paper is that mobile application use in agriculture cannot be explained adequately by availability or farmer attitudes alone. Instead, use emerges from the interaction of five domains: the perceived agronomic value of the application; its inclusive usability and accessibility; its contextual and cultural fit; the trust and transparency it affords; and its embeddedness in social and institutional networks. These domains interact with the infrastructural and personal circumstances of farmers, including connectivity, device quality, data affordability, gender, age, education, and prior digital experience.

Our paper is a contribution to mobile HCI rather than a new theory of adoption. We make two proposals. First, we propose agriculture as a field-use context that exposes the limits of generic mobile usability and of standard technology adoption models. Second, we propose that adoption and use are a function of five domains: agronomic value, field usability, contextual fit, trust calibration, and social–institutional embeddedness. In treating agriculture as an important setting for inclusive, citizen-centered mobile HCI, the paper responds directly to the present special issue’s emphasis on participatory, accessible, and equitable mobile systems.

We use the term *field-ready HCI* to name the standard of interaction design that these conditions demand, and we define it explicitly. Field-ready HCI is the design and evaluation of mobile interfaces for (i) outdoor field use under sun, glare, time pressure, and soiled hands; (ii) weak, intermittent, or costly network environments; (iii) low-end, shared, or borrowed devices; (iv) users with low literacy or limited digital experience; (v) local languages, idioms, units, and crop terminology; (vi) the high-risk nature of agricultural advice, where a single mistaken recommendation can destroy a crop or waste scarce cash; (vii) the embedding of local and indigenous knowledge; and (viii) coordination with agricultural extension and farmer networks rather than the individual office worker assumed by mainstream design. Field-ready HCI is thus distinct from generic mobile HCI, which assumes benign indoor conditions; from HCI4D, which addresses low-resource interaction in general but not agricultural decision-making and its risks; and from information and communication technologies for agriculture (ICT4Ag), which has emphasized service delivery and adoption more than the moment of interaction. We position the contribution accordingly: the paper offers an agriculturally contextualized integration of established technology acceptance theories and HCI4D, not a wholly new theory of adoption.

Two scope conditions should be stated at the outset. First, this is a conceptual contribution. We develop a model and propositions but do not test them: the relationships we describe are theoretically grounded and, we argue, plausible, but they have not yet been validated with empirical data, expert elicitation, case mapping, or user studies. The research agenda in Section 6 is a plan for such validation, not a substitute for it. Second, the model is oriented to low-resource and smallholder contexts and may require adaptation for commercial or highly mechanized agriculture.

Accordingly, we develop an HCI model and associated propositions of mobile application use in low-resource, rural, and smallholder agricultural contexts. Three research questions orient our discussion: (RQ1) What HCI, socio-technical, and agricultural factors explain sustained mobile application use in agriculture? (RQ2) How do usability, trust, contextual fit, and participatory design influence farmers’ engagement with agricultural applications? (RQ3) What propositions can guide future empirical testing of mobile application adoption, use, and impact in agricultural settings? The remainder of our paper reviews the relevant literature, sets out its theoretical foundations, presents the model and its propositions, outlines a research agenda for testing and applying it, and discusses contributions and implications.

2. Mobile Applications in Agriculture: A Brief Synthesis

Mobile applications used in agriculture are heterogeneous in purpose and form. We classify them by their primary function, the main agricultural task they support and, with it, the characteristic interaction challenge they pose, rather than by platform, business model, or underlying technology. The four types below are therefore analytical categories intended to organize an HCI analysis; they are not mutually exclusive, and many real applications span several (a market application may also deliver advisory content, and a precision agriculture tool may include a participatory reporting feature). For the purposes of an HCI analysis, it is useful to distinguish four broad and overlapping types, each of which raises characteristic interaction challenges.

2.1. *Advisory and Extension Applications*

Advisory applications deliver guidance on planting dates, pest and disease management, fertilizer use, irrigation, animal health, and climate adaptation. They build on a long tradition of using information and communication technologies to extend the reach of agricultural advice, on the premise that mobile channels can serve more farmers, more cheaply, than conventional systems [1,3]. However, evidence suggests that information alone does not change practice. Advice lands only when it is timely, local, clear, actionable, and trusted; otherwise, farmers ignore it.

2.2. *Market, Finance, and Transaction Applications*

A second category supports price discovery, produce marketing, input purchasing, logistics, digital payments, credit, and insurance. These applications target the transaction-cost problems that disadvantage smallholders, including weak bargaining power, information asymmetry, and limited access to buyers [2,10,11]. Mobile money and digital marketplaces can improve coordination, but they can also reproduce exclusion: farmers who lack identity documents, digital literacy, suitable devices, or stable connectivity may be left behind.

2.3. *Farm-Management and Precision-Agriculture Applications*

A third category comprises farm-recording tools, decision dashboards, remote-sensing interfaces, crop-monitoring systems, applications linked to the Internet of Things, and image-based pest or disease diagnosis [2,5,12]. The HCI problem is how to visualize complex data, how to render automated recommendations explainable, and how to calibrate trust in advice that the farmer cannot independently verify. As such applications increasingly incorporate AI, the usability of the interface determines whether that intelligence is used.

2.4. *Participatory, Community, and Citizen-Centered Applications*

A fourth category centers on farmer participation, local knowledge sharing, peer learning, cooperative action, participatory pest surveillance, and community-based adaptation. This work overlaps with citizen-centered HCI and participatory design, and it is especially pertinent in agriculture. Studies of women farmers, for instance, show that values such as accessibility, security, independence, accuracy, and social recognition are routinely overlooked when application design is insufficiently participatory [9,13,14].

Scoping and systematic reviews report a proliferation of advisory, market, and information dissemination services coupled with persistent obstacles: limited connectivity, the cost of data and devices, low digital literacy, language barriers, gendered access to phones, and weak integration with existing extension systems [5,6]. Country-level studies echo these findings: investigations of mobile technology for agricultural information among

smallholders in Zimbabwe, and of application adoption in Nigeria, point to exposure, perceived benefit, trust, and supporting infrastructure as recurring determinants of whether tools are used in practice [15,16]. The pattern that emerges is consistent with our argument: availability and even perceived usefulness are necessary but not sufficient; the conditions of use frequently decide outcomes [17].

It is useful, before turning to the gap, to separate three things that the literature often runs together: availability, adoption, and sustained use. Availability is whether a suitable application exists and can in principle be obtained. Adoption is whether a farmer installs or first tries it. Sustained use is whether the farmer continues to use it across tasks and seasons, and whether use actually changes decisions. These come apart in practice: applications that are widely available are not always adopted; many that are adopted after promotion or subsidy are abandoned within a single season; and some that are used routinely never alter a decision. Explaining the slippage between availability, adoption, sustained use, and impact is precisely what acceptance accounts of “usefulness” leave unexplained. It is the slippage that our three use stages (adoption intention, sustained use, and decision impact) capture.

2.5. The Gap

Across these categories, studies explain agricultural application use mainly through acceptance, diffusion, and utility models. We suggest that such accounts are incomplete. The gap they leave is not a shortage of variables but a missing level of analysis: the interaction-level and infrastructure-level mechanisms through which farmers actually encounter, evaluate, trust, adapt, and sustain application use in everyday agricultural work. Supplying this level of analysis is the goal of our paper.

What unites the four categories is not their content but the conditions under which their interfaces are encountered. An advisory message, a market price, a sensor dashboard, and a community pest report are very different payloads, yet each must be perceived, understood, trusted, and acted upon by the same farmer, on the same constrained device, in the same field, under the same infrastructural limits. The recurring failure points are correspondingly similar across categories, i.e., illegibility under field conditions, language and literacy barriers, opaque or unexplained recommendations, mismatch with local practice, and dependence on connectivity and intermediaries. They are precisely the points that acceptance, diffusion, and utility models address only obliquely. Table 1 makes this convergence explicit, mapping each application type to its main use scenarios, its typical interaction barriers, the corresponding limitation in existing research, and the model construct (developed in Section 4) intended to address it. Read down its final column, the table previews the five antecedent domains and shows that they are not arbitrary: each answers a barrier that recurs across application types, which is the sense in which the categories collectively point to a single requirement of field-ready HCI.

Table 1. Application types mapped to use scenarios, typical interaction barriers, the corresponding limitation of existing research, and the model construct intended to address them.

Application Type	Main Use Scenarios	Typical Interaction Barriers	Limitation in Existing Research	Corresponding Model Construct
Advisory and extension	Planting dates, pest and disease management, fertilizer, irrigation, animal health, climate adaptation	Advice not timely, local, or actionable; text-heavy screens; language and literacy barriers; unexplained recommendations	Acceptance and diffusion models treat “usefulness” as global rather than as timely, local, actionable advice acted on in the field	Perceived agronomic value; trust and transparency

Table 1. Cont.

Application Type	Main Use Scenarios	Typical Interaction Barriers	Limitation in Existing Research	Corresponding Model Construct
Market, finance and transaction	Price discovery, produce marketing, input purchasing, logistics, payments, credit, insurance	Identity and literacy requirements; complex multi-step flows; exclusion of those without devices, connectivity, or documents	Transaction-cost framing overlooks who is excluded by interface and infrastructure	Inclusive usability and accessibility; social and institutional embeddedness
Farm management and precision agriculture	Record-keeping, dashboards, remote sensing, crop monitoring, IoT, image-based diagnosis	Complex data visualization; opaque or unverifiable AI recommendations; trust calibration	Utility models are largely silent on explainability and on trust in advice the farmer cannot verify	Trust and transparency; inclusive usability
Participatory, community and citizen-centered	Knowledge sharing, peer learning, cooperative action, participatory surveillance, community adaptation	Non-participatory design overlooks users' values (e.g., women farmers); weak fit with local practice and knowledge	Adoption models under-weight values, culture, and participation	Contextual and cultural fit; social and institutional embeddedness

To make this synthesis explicit and to ground our model in prior work, Table 2 maps the five antecedent domains developed in Section 4 to representative literature, key findings, and their implications for field-ready HCI. The mapping shows that, while the constructs have clear antecedents in established theory, their value for agriculture lies in their re-specification for agricultural field conditions.

Table 2. Mapping of the model's five antecedent domains to supporting literature, key findings, and design implications.

Antecedent Domain	Representative Literature	Key Findings	HCI/Design Implications
Perceived agronomic value	Davis [18]; Muromba et al. [7]; Okoroji et al. [16]	Perceived usefulness is a leading determinant of adoption; in smallholder settings, tangible farming benefit often outweighs interface elegance.	Foreground locally relevant, timely, actionable advice tied to concrete decisions (planting, inputs, pests, markets).
Inclusive usability and accessibility	Ho et al. [19]; Medhi et al. [20]; Medhi Thies [8]	Low-literacy and novice users benefit from voice-, icon- and image-based, non-textual designs; weak usability can prevent usefulness from ever being discovered.	Design for low cognitive load, local-language, offline-first, error-tolerant operation under field conditions.
Contextual and cultural fit	Rogers [21]; Shams et al. [9,13]	Compatibility with local practices, language, and norms drives diffusion; women farmers' values (accessibility, security, recognition) are overlooked when design is not participatory.	Achieve fit through participatory design aligned to local crops, calendars, units, gender roles, and terminology.

Table 2. Cont.

Antecedent Domain	Representative Literature	Key Findings	HCI/Design Implications
Trust and transparency	Venkatesh et al. [22]; Dara et al. [23]	Willingness to act on advice, especially AI-generated advice, depends on source credibility, explainability, and the perceived fairness of data practices.	Provide explanation-on-tap, source-transparency signals and clear data-ownership and consent practices.
Social and institutional embeddedness	Venkatesh et al. [22]; Mhlanga & Ndhlovu [6]; Musungwini et al. [15]; Choruma et al. [5]	Adoption and sustained use hinge on facilitating conditions, extension endorsement, peer networks, and supporting infrastructure.	Integrate apps with extension workers, cooperatives, and service ecosystems; treat human intermediaries as complements, not replacements.

3. Theoretical Foundations

Our proposed model integrates four established traditions in technology adoption with the HCI literature, and in particular with human–computer interaction for development (HCI4D). Why integrate several theories rather than extend one? Because the phenomenon is multi-level, and each source theory is silent on a level that matters in agriculture. TAM models individual perceptions of usefulness and ease but cannot represent the institutional embeddedness of things like cooperative membership and agro-dealer relationships, through which agricultural tools actually reach farmers. UTAUT adds facilitating conditions and social influence but treats the interface itself as given and so does not account for field-based usability. Diffusion of innovations explains spread through compatibility and observability but has little to say about the transparency of AI-generated advice or the data-ethics conditions of trust. HCI4D supplies exactly those interaction- and infrastructure-level concerns, but, on its own, does not explain why a farmer would intend to adopt a tool in the first place, or how value, trust, and social endorsement combine to sustain use. Integration is therefore not eclecticism but necessity: only a combined account spans perception, interface, diffusion, and infrastructure. Table 3 sets out, for each source theory, the core construct we draw on, the model domain it maps to, and the agricultural re-specification we apply.

Table 3. Integration of source theories: core constructs drawn on, the corresponding domain in the proposed model, and the agricultural-contextualized extension applied.

Source Theory	Core Construct(s) Drawn On	Corresponding Model Domain	Agricultural-Contextualized Extension
TAM [18]	Perceived usefulness; perceived ease of use	Perceived agronomic value; inclusive usability	Usefulness re-specified as timely, local, actionable agronomic benefit tied to concrete decisions
UTAUT [22]	Performance and effort expectancy; social influence; facilitating conditions	Inclusive usability; social and institutional embeddedness; contextual constraints	Facilitating conditions split into infrastructure, affordability, demographic, and digital-capability constraints; social influence located in extension and cooperative networks

Table 3. Cont.

Source Theory	Core Construct(s) Drawn On	Corresponding Model Domain	Agricultural-Contextualized Extension
Diffusion of innovations [21]	Relative advantage; compatibility; trialability; observability	Contextual and cultural fit; social and institutional embeddedness	Compatibility broadened to cropping systems, language, seasonal rhythm, gendered labor, local units, and traditional knowledge; modeled as indirect
HCI4D, HCI and UX [8,19,20]	Usability, accessibility, cognitive load, low-literacy and voice/icon design	Inclusive usability and accessibility	Re-specified for outdoor, intermittent-connectivity, shared-device “field-ready” conditions
Socio-technical systems, human values and data ethics [9,13,23]	Institutional embedding; values (fairness, privacy, autonomy); explainability; data ownership and consent	Trust and transparency; social and institutional embeddedness	Explainability and data ethics treated as facets of trust; human values as facets of contextual fit

3.1. The Technology Acceptance Model

TAM holds that perceived usefulness and perceived ease of use shape behavioral intention and, in turn, technology use [18]. Agricultural applications of TAM frequently extend it with constructs such as trust, awareness, compatibility, self-efficacy, information quality, and social influence. Reviews of mobile agricultural services suggest that perceived usefulness is often a stronger predictor of adoption than ease of use, especially in smallholder settings where tangible farming value may outweigh interface elegance [7]. HCI research, however, cautions against treating ease of use as secondary. In low-literacy, multilingual, rural, or older-user contexts, usability can determine whether usefulness is ever discovered at all: an application whose value is locked behind an unusable interface is, for many farmers, simply not useful.

3.2. UTAUT and Social Influence

UTAUT emphasizes performance expectancy, effort expectancy, social influence, and facilitating conditions [22]. It is well suited to agriculture because farming decisions are socially embedded. Farmers learn through peers, family members, lead farmers, extension officers, agro-dealers, cooperatives, and demonstration plots; social proof and local endorsement consequently influence both initial adoption and continued use. UTAUT also foregrounds facilitating conditions, which anticipates the infrastructural constraints treated explicitly in our model.

3.3. Diffusion of Innovations

Diffusion theory explains adoption through relative advantage, compatibility, complexity, trialability, and observability [21]. Agricultural applications are more likely to diffuse when they fit existing practices, produce visible benefits, can be tried at low risk, and are promoted through trusted networks. The theory also explains failure: technically sound applications may be rejected when they conflict with farmers’ routines, terminology, local calendars, or social norms. Compatibility, in particular, is a precursor of the contextual-fit domain developed below.

3.4. Human–Computer Interaction, User Experience, and HCI4D

HCI contributes variables that adoption theory tends to underplay: usability, accessibility, cognitive load, interaction design, information architecture, feedback, affordances,

error tolerance, interface transparency, and emotional experience. HCI4D extends these concerns to developing-region contexts, studying how interactive systems can be designed for the distinctive needs of users in such settings and for the difficult infrastructures in which the systems must operate [19,24]. A substantial HCI4D literature documents strategies for novice and low-literacy users, such as voice interfaces, icon- and image-based navigation, and non-textual designs that reduce reliance on reading [8,20]. Agriculture intensifies these concerns. Application use commonly occurs outdoors, under time pressure, in bright sunlight, with soiled hands, over intermittent connectivity, on shared or low-specification devices, across multiple languages, and in support of high-stakes decisions. We describe the resulting requirement as “field-ready HCI”: a standard of interaction design calibrated to agricultural field conditions rather than to generic mobile usability.

More recent HCI4D and adjacent work has moved beyond the classic low-literacy interface toward concerns that agriculture makes urgent: the design of AI-assisted advisory tools and the explainability of their recommendations [25,26]; participatory and value-sensitive design that surfaces what users such as women farmers actually care about [9,13,27]; digital inclusion and the gendered, generational, and infrastructural divides that determine who can participate at all; and the data ethics of increasingly data-intensive platforms, including ownership, consent, and algorithmic fairness [23]. Our model absorbs these strands rather than treating them as separate: explainability and data ethics enter through trust and transparency (Domain 4), participatory and value-sensitive design through contextual and cultural fit (Domain 3), and digital inclusion through inclusive usability (Domain 2) together with the contextual constraints that moderate every path.

3.5. Socio-Technical Systems, Human Values, and Data Ethics

Socio-technical systems theory insists that technologies are embedded in institutional, economic, cultural, and infrastructural arrangements [28]. A farmer’s ability to use an application depends not only on the interface but also on mobile coverage, data costs, extension support, input availability, market access, gendered patterns of phone ownership, and trust in the organizations that supply data. Research on human values further shows that applications fail when they violate user expectations around fairness, privacy, security, autonomy, or respect [9,13,27]. As agricultural applications become more data-intensive and AI-enabled, these concerns acquire an explicit ethical dimension: questions of data ownership and consent, of algorithmic fairness, and of the transparency of automated recommendations bear directly on whether farmers are willing to rely on the systems at all. Our model treats these matters as facets of trust.

4. A Core HCI Model of Mobile Application Use in Agriculture

Our model proposes that mobile application use in agriculture is driven by five antecedent domains, each of which plays one primary role across three use stages: adoption intention, sustained use, and decision impact. Perceived agronomic value principally drives adoption; inclusive usability principally drives sustained use; contextual and cultural fit amplifies both by raising value and usability; trust and transparency convert use into decision impact; and social and institutional embeddedness legitimizes and supports both adoption and continued use. Contextual constraints of infrastructure and farmer characteristics moderate these relationships. The model deliberately omits a separate mediator layer and treats empowerment as part of the final outcome, in the interest of parsimony and testability. Figure 1 outlines our model.

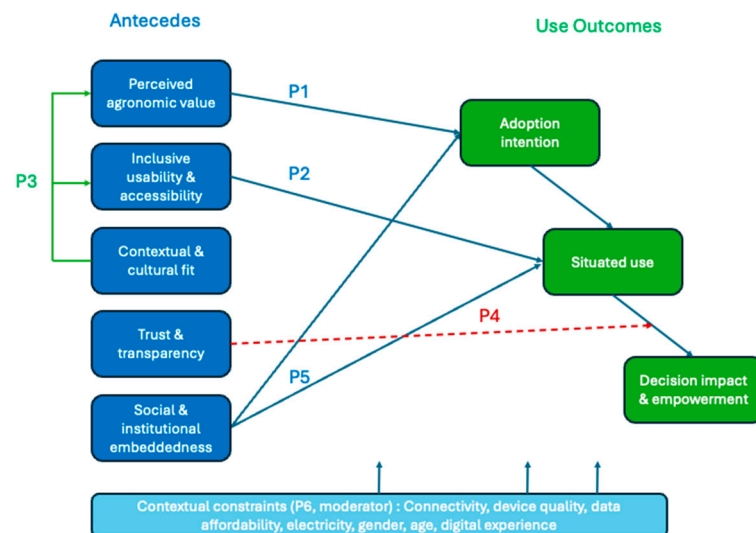


Figure 1. A core HCI model of mobile application use in agriculture. Five antecedent domains drive the adoption → sustained use → decision impact sequence; trust (P4) and contextual constraints (P6) act as moderators, shown with dashed arrows. Labels P1–P6 correspond to the propositions in Section 5.

4.1. Model Development Procedure

To make the model’s construction traceable rather than asserted, we set out the five-step procedure by which it was developed.

First, literature scope. We assembled sources from four bodies of work: technology-acceptance and diffusion research applied to agriculture (TAM, UTAUT, and diffusion studies and reviews); HCI4D and low-literacy interaction design; socio-technical systems, human-values, and data-ethics research; and country- and service-level studies of mobile agriculture in low-resource settings. The aim was analytical coverage of the mechanisms named across this literature, not an exhaustive systematic review.

Second, candidate construct extraction. From these sources, we extracted the constructs repeatedly invoked to explain agricultural application use—among them, perceived usefulness, perceived ease of use, compatibility, relative advantage, trust, source credibility, explainability, social influence, facilitating conditions, usability, accessibility, cognitive load, language and literacy fit, cultural fit, data ownership and consent, self-efficacy, satisfaction, and institutional support.

Third, construct merging. We grouped candidates that share an underlying mechanism and are difficult to separate empirically under field conditions. Perceived usefulness was re-specified as perceived agronomic value; usability, accessibility, cognitive load, and low-literacy support were merged into inclusive usability; compatibility together with cultural and linguistic fit became contextual and cultural fit; source credibility, explainability, and data ethics were folded into trust and transparency; and social influence, facilitating conditions, and institutional support became social and institutional embeddedness.

Fourth, retention and exclusion. We retained a construct as a separate domain only if it (i) recurred across the literature, (ii) had a distinct HCI or infrastructural mechanism, and (iii) could plausibly be measured in the field. Constructs better understood as consequences (digital self-efficacy, user satisfaction) or as mechanisms internal to another domain (AI explainability, participatory design) were folded in rather than listed separately, in the interest of parsimony and testability. This yields five domains that we argue are jointly sufficient to organize the recurring explanations in the source literature and individually necessary, in the sense that dropping any one leaves a documented class of failure unexplained: value (irrelevant advice), usability (an unusable interface), fit (mismatch with local

practice), trust (advice that is not believed), and embeddedness (the absence of social or institutional support). We do not claim that no other carving of the space is possible; we claim that this one is parsimonious, traceable, and testable.

Fifth, path and proposition logic. We assigned each domain a primary role across the three use stages on theoretical grounds. Value drives adoption intention, usability drives sustained use, fit raises both indirectly, trust converts use into impact, and embeddedness supports adoption and sustained use. We represented contextual constraints as moderators rather than causes. The six propositions in Section 5 state these roles as testable claims, each labeled as an antecedent, a mediator, or a moderator.

4.2. Use Outcomes

The model distinguishes three outcomes. Adoption intention is the willingness to try or install an application. Sustained use is repeated use across agricultural tasks and seasons. Decision impact and empowerment denote the application's influence on farming decisions, productivity, income, risk reduction, and sustainability, together with farmers' sense of autonomy and control. Empowerment is understood here in a deliberately narrow sense: farmers' expanded capability to make and act on agronomic decisions on their own terms, evidenced by greater autonomy, confidence, and control in the decision process, rather than as a diffuse notion of well-being. Separating the three matters because they can diverge sharply: a farmer may install an application but never use it, use it once and abandon it, or use it regularly without it changing any decision. Explaining sustained, consequential use, not mere installation, is the model's goal.

4.3. Domain 1: Perceived Agronomic Value

Perceived agronomic value is the farmer's judgment that an application delivers useful, timely, local, and actionable agricultural benefit. It extends TAM's perceived usefulness by making usefulness domain-specific: an application is valuable not in the abstract but because it helps the farmer decide when to plant, how much fertilizer to apply, how to respond to a pest outbreak, where and when to sell, or whether to irrigate. Its dimensions include relevance to the farmer's crop, livestock, or production system; local specificity; timeliness; actionability; economic usefulness; and risk-reduction potential. Perceived agronomic value is our model's principal driver of adoption intention.

4.4. Domain 2: Inclusive Usability and Accessibility

Inclusive usability and accessibility concern whether farmers with low literacy, limited digital skills, older age, or disability, and those using shared phones or facing intermittent connectivity, can use an application effectively. This domain translates HCI4D principles into the agricultural field. Its dimensions include low cognitive load, clear navigation, local-language interfaces, voice and icon- or image-based support, offline or low-bandwidth functionality, error tolerance, and usability under field conditions. Inclusive usability is the model's principal driver of sustained use: where initial adoption may be prompted by promotion or curiosity, continued use depends on whether the application can be operated during real agricultural work. Constructs sometimes modeled separately, such as digital self-efficacy and user satisfaction, are treated here as consequences of good usability rather than as additions.

4.5. Domain 3: Contextual and Cultural Fit

Contextual and cultural fit is the alignment between an application and the farmer's local practices, social norms, seasonal rhythms, crop calendars, gender roles, and decision-making arrangements. It extends the compatibility construct of diffusion theory while giving it stronger cultural and HCI grounding. Crucially, contextual fit acts as an amplifier

rather than a direct cause of an outcome: an application that reflects local crops, language, climate, pests, units of measurement, and routines is both more useful and easier to use. Its dimensions include alignment with local farming systems; cultural and linguistic adaptation; fit with seasonal workflows; fit with gendered patterns of phone access and labor; fit with local units, measures, crops, pests, and terminology; and respect for local knowledge. Participatory design is the principal route by which contextual fit is achieved.

4.6. Domain 4: Trust and Transparency

Trust is what converts use into impact. Agricultural decisions are consequential: a mistaken recommendation can destroy a crop and waste scarce money, and thus farmers will act on an application's advice only to the extent that they trust its data and recommendations. This domain encompasses the credibility of the information source, the transparency of recommendation logic, confidence in data accuracy, the explainability of AI-enabled advice, privacy and data-ownership expectations, the perceived fairness of the application and its provider, and trust in the sponsoring institution. AI explainability and data ethics are thus treated as facets of trust rather than as separate constructs: a recommendation that the farmer cannot understand, or that arrives from a provider whose data practices seem opaque or unfair, is unlikely to change behavior, however accurate it may be.

4.7. Domain 5: Social and Institutional Embeddedness

Agricultural application use is embedded in advisory systems, cooperatives, peer networks, agro-dealer relationships, government programs, non-governmental organizations, and platform ecosystems. Trusted intermediaries reduce perceived risk and confer legitimacy, supporting both adoption and continued use. The domain's dimensions include extension-worker endorsement, peer use and recommendation, integration with cooperatives or farmer groups, demonstrations and training, links to input, credit, insurance, or market services, and institutional legitimacy. From a citizen-centered perspective, these intermediaries are the civic and community infrastructure through which public-good applications reach farmers and remain in use.

4.8. Contextual Constraints

Finally, our model situates these relationships within a set of contextual constraints that moderate, rather than cause, application use. For operational clarity we group them into four categories: (i) infrastructure constraints (network connectivity, electricity access, and device quality); (ii) economic accessibility constraints (data affordability and device and service cost); (iii) demographic characteristics (gender, age, and education); and (iv) digital-capability characteristics (prior digital experience, digital literacy, and self-efficacy). Their effect is to strengthen or weaken the domain–outcome relationships. Most importantly, even a well-designed and trusted application will fail to sustain use where these constraints bind: a point that distinguishes field-ready HCI from usability in better-resourced settings.

5. Testable Propositions

Our model yields six propositions: one for each of the five antecedent domains, naming that domain's primary effect, together with a sixth that specifies the moderating role of contextual constraints. Each proposition details whether the construct is expected to act as an antecedent, a mediator, or a moderator, so that the claims can be operationalized. Together, they describe a path from antecedents to outcomes that can be converted into hypotheses for survey, mixed-methods, experimental, or design-science research.

Proposition 1 (agronomic value influences adoption intention; antecedent). *The greater the perceived agronomic value of a mobile agricultural application, the stronger the farmer’s intention to adopt it. Value is grounded in concrete decisions, such as pest control, weather response, input selection, market timing, or livestock management. Applications perceived to bear directly on such decisions are the most likely to be taken up.*

Proposition 2 (inclusive usability influences sustained use; antecedent). *The more inclusive an application’s usability, the more likely use is to be sustained. This effect is primarily on sustained use rather than on initial adoption. Farmers may adopt an application in response to promotion, social influence, or curiosity, but they continue using it only when it can be operated easily during real agricultural work, under field conditions and with whatever device, connectivity, and literacy they possess.*

Proposition 3 (contextual fit influences value and usability; indirect effect on outcomes; mediator pathway). *The better an application’s contextual and cultural fit, the higher its perceived agronomic value and its usability. An application that reflects local crops, language, climate, pests, units, and routines is at once more useful and easier to use; contextual fit therefore operates indirectly on the outcomes, by raising the two domains that drive them. Formally, contextual fit is modeled as exerting an indirect, mediated effect on adoption intention and sustained use through perceived agronomic value and inclusive usability, rather than acting directly on either outcome. Contextual fit extends, but is not identical to, diffusion theory’s compatibility. Compatibility, as classically defined, concerns consistency with existing values, past experience, and needs, and is treated as a direct antecedent of adoption. Contextual fit is broader in content and different in function: broader because it explicitly incorporates agricultural specifics, and different in function because we model it as acting indirectly, through value and usability, rather than directly on adoption. This proposition also implies that participatory design, as the principal means of achieving fit, should improve both value and usability.*

Proposition 4 (trust influences decision-impact relationship; moderator). *Trust in the information source, data quality, and recommendation transparency positively moderates the relationship between sustained application use and agricultural decision impact: a given level of use yields greater decision impact when trust is high than when it is low. Useful advice changes behavior only when its source, data, and logic are trusted and, where relevant, explainable. We model trust principally as a moderator because its most distinctive work is to govern whether a farmer acts on advice that is already being received. We acknowledge, however, that trust may also exert direct effects on adoption intention and sustained use. A credible sponsor can encourage installation, and confidence in recommendations can encourage continued use. We treat these as plausible secondary paths and as an explicit alternative specification to be tested: empirical work should estimate both the moderating effect posited here and the possible direct effects, and compare them. Foregrounding moderation reflects the model’s parsimony and its focus on the conversion of use into consequence, not a denial of the direct paths. Trust is especially decisive for data-intensive and AI-enabled applications.*

Proposition 5 (social embeddedness influences adoption and sustained use; antecedent). *The more an application is embedded in social and institutional networks, such as cooperatives and farmer groups, the more likely it is to be adopted and sustained. Endorsement by trusted intermediaries provides social proof and perceived legitimacy that lower the perceived risk of adoption and reinforce continued use.*

Proposition 6 (contextual constraints moderate the model; moderator). *Contextual constraints moderate the relationships between the five antecedent domains and the use outcomes. For operational clarity, we group them into four categories: (i) infrastructure constraints (network connectivity, electricity, and device quality); (ii) economic accessibility constraints (data affordability and device and service cost); (iii) demographic characteristics (gender, age, and education); and (iv) digital capability characteristics (prior digital experience, digital literacy, and self-efficacy). The effects of the five domains, and especially of contextual fit, trust, and social and institutional embeddedness, are weakened wherever these constraints bind. Even a well-designed and trusted application will therefore fail to sustain use, or to translate, use into impact, where the enabling infrastructure, affordability, or digital capability is absent.*

Two features of our model should be emphasized. First, it is deliberately parsimonious. Mechanisms that might be modeled separately (i.e., explainability of AI advice, participatory design, and digital self-efficacy and satisfaction) are folded into the five antecedent domains, keeping the propositions directly testable. Second, the moderating role of context is stated explicitly in Proposition 6, so that the benefits of the five antecedent domains are treated as conditional on adequate infrastructure and on farmer characteristics rather than as guaranteed.

Illustrating the Model: A Worked Example

To show how the model applies in practice and to illustrate the six propositions, consider the following hypothetical but realistic case; it is offered as an illustration of how the model would be used, not as empirical evidence. Asha is a smallholder who grows maize on about one hectare in a rural district with intermittent network coverage. Her cooperative, working with a national agricultural research institute and a local extension officer, promotes a free advisory application that offers image-based diagnosis of fall armyworm, localized planting and spraying guidance, and market prices, delivered in her language with voice prompts, icon-based navigation, and offline operation on the low-specification phone she shares with her household.

The five domains structure how Asha comes to adopt, sustain, and act on the application. Because the app speaks to a concrete and costly decision (whether and how to treat an armyworm outbreak that could destroy her crop), its perceived agronomic value is high, and this drives her intention to adopt it (Proposition 1). Whether she keeps using it across the season depends less on that first impression than on inclusive usability: the voice and icon interface, offline operation, and local-language support let her operate the app in the field, under poor connectivity and on a shared device, so that use is sustained (Proposition 2). These benefits are not independent of context. Because the application reflects her crop, her local pest, her calendar, her units, and her language, it is at once more useful and easier to use; contextual and cultural fit therefore raises both value and usability rather than acting on adoption directly (Proposition 3). When the app diagnoses armyworm and recommends a control, Asha acts on the advice only if she trusts it: an explanation-on-tap that conveys why the diagnosis was made, a visible indication that the advice originates with the national research institute, and her cooperative's endorsement together make the recommendation credible enough to change what she does, converting use into agronomic impact (Proposition 4). That endorsement matters earlier too: because a trusted cooperative and extension officer recommend the app, and because her peers already use it, the perceived risk of adopting and continuing with it falls (Proposition 5).

These mechanisms are, finally, conditional. If coverage is too patchy to return a diagnosis, if the shared phone is seldom available when a decision is due, or if data costs make Asha reluctant to open the app at the moment of need, then even this well-designed and trusted application will fail to sustain use or to translate use into impact (Proposition 6).

Table 4 sets out how each domain and proposition appears in the example. We emphasize again that the case is illustrative: it shows how the model would be applied and how its propositions might be observed and tested, rather than offering evidence that the relationships hold: an empirical task outlined in the research agenda of Section 6.

Table 4. Illustrative application of the model’s five domains and six propositions to the worked example.

Domain (Proposition)	How It Appears in the Worked Example	Modeled Effect
Perceived agronomic value (P1)	The app targets a concrete, costly decision—controlling a fall-armyworm outbreak that could destroy the maize crop.	Drives adoption intention.
Inclusive usability and accessibility (P2)	Voice and icon interface, offline operation, and local language let Asha operate the app in the field on a shared, low-specification phone.	Drives sustained use.
Contextual and cultural fit (P3)	The app reflects her crop, local pest, season, units, and language.	Raises value and usability; indirect effect on outcomes.
Trust and transparency (P4)	Explanation-on-tap for the diagnosis, a visible institutional source, and cooperative endorsement make the advice credible enough to act on.	Moderates the conversion of use into decision impact.
Social and institutional embeddedness (P5)	Cooperative and extension-officer endorsement and visible peer use lower the perceived risk of trying and continuing.	Supports adoption and sustained use.
Contextual constraints (P6)	Patchy coverage, limited access to the shared phone, and data costs can each intervene.	Moderates (weakens) the domain–outcome relationships.

6. A Research Agenda for Testing and Applying the Model

The present paper offers no empirical test: it contributes a conceptual model, and the approaches below describe how that model could be validated rather than reporting validation already performed. To test the model, complementary approaches are proposed, and are described in turn.

6.1. Design Science and HCI Evaluation

A design science study could develop or refine an agricultural application that instantiates the five domains—for example, a local-language interface with voice and icon support, offline-first operation, explanation-on-tap for AI-generated advice, and explicit source transparency. The prototype could then be evaluated under realistic conditions using task-completion measures, usability testing, think-aloud protocols, farmer satisfaction ratings, and field-based use logs. This track offers the most direct route from model to artifact and provides concrete evidence of the model’s practical value.

6.2. Quantitative Model Testing

A survey-based study could measure the model’s constructs using scales adapted from TAM, UTAUT, diffusion theory, established HCI usability measures, the trust literature, and agricultural extension research. Structural equation modeling would be appropriate for testing the path relationships among the five domains and the three use outcomes, with infrastructure and farmer characteristics specified as moderators. Candidate samples include smallholders using advisory applications, commercial farmers using precision agriculture tools, women farmers using cooperative or extension applications, and extension workers supporting deployment, ideally across more than one country to support generalization.

6.3. Qualitative and Participatory Inquiry

Qualitative research could examine how farmers interpret recommendations, negotiate trust, share devices, incorporate advice into practice, and experience barriers. Interviews, focus groups, participatory design workshops, diary studies, and field observation would illuminate the meanings and constraints that quantitative measures cannot capture, and would help refine the domains for particular crops, regions, and user groups.

6.4. An Integrated Program

A strong empirical contribution could combine these approaches in sequence: participatory workshops to identify farmer needs and values; prototype development on HCI4D principles; field usability testing; survey-based testing of the model; analysis of application analytics to assess sustained use; and interviews to interpret patterns of adoption and abandonment. Such a program would test the model while simultaneously demonstrating its use as a design tool.

7. Discussion

We set out to answer three research questions, and the model and its propositions provide conceptual answers to each. In response to RQ1 (which HCI, socio-technical, and agricultural factors explain sustained mobile application use in agriculture?), the paper identifies five antecedent domains (perceived agronomic value, inclusive usability and accessibility, contextual and cultural fit, trust and transparency, and social and institutional embeddedness) that operate across the stages of adoption intention, sustained use, and decision impact and are conditioned by infrastructural and farmer-level constraints. In response to RQ2 (how usability, trust, contextual fit, and participatory design shape farmers' engagement), the model assigns distinct roles: inclusive usability principally sustains use; trust principally governs whether use is converted into decision impact; contextual fit operates indirectly by raising both value and usability; and participatory design is identified as the principal route through which contextual fit is achieved. In response to RQ3 (what propositions can guide future empirical testing), the paper offers six testable propositions (P1–P6) that turn these mechanisms into directional, operationalizable claims, together with the research agenda in Section 6. Consistent with the conceptual aim of this study, these are analytical results rather than empirical findings.

Our model makes several contributions. First, it contributes to mobile HCI by situating application use in a demanding rural, outdoor, multilingual, and resource-constrained environment. Agriculture stretches standard assumptions about mobile design, because use frequently occurs under field conditions rather than in offices or homes; the notion of field-ready HCI names this distinctive requirement and roots it in the HCI4D tradition [8,19].

Second, it contributes to agricultural technology adoption theory by extending perceived usefulness into perceived agronomic value and by integrating trust, contextual fit, and inclusive usability into a single, parsimonious model. In doing so, it addresses the principal limitation of acceptance and diffusion-based studies: their relative silence on interaction- and infrastructure-level mechanisms, while remaining compatible with their established constructs. The contribution is thus one of re-specification and integration rather than of new constructs: the paper offers an HCI-sensitive specification of mobile application use under agricultural field conditions, not a new theory of adoption.

Third, it contributes to research on information and communication technologies for agriculture and on digital extension by explaining why the delivery of information alone is insufficient. Applications work best when embedded in social networks, institutional support, extension relationships, and practical service ecosystems; the social and institutional embeddedness domain makes this dependence explicit.

Fourth, it contributes to responsible and data-driven agriculture by identifying trust, transparency, explainability, and data ethics as central HCI concerns for AI-enabled applications, rather than as peripheral compliance issues. As predictive analytics, remote sensing, and image recognition become more common, the willingness of farmers to act on automated advice will depend heavily on whether that advice can be understood and whether the data practices behind it are perceived as fair [26].

Finally, the model contributes to a citizen-centered HCI agenda by treating farmers as citizens and agricultural applications as public-good infrastructure. This framing, which emphasizes empowerment, community engagement, and inclusive provision, aligns the study of agricultural applications with broader concerns about equity and participation in digital systems. This public-good framing should not be overstated, however. Not all agricultural applications are public infrastructure: many are commercial platforms whose data practices may be extractive and whose accumulation of farm data can shift market power away from farmers. A citizen-centered analysis must therefore hold this tension in view, treating data ownership, consent, and fairness as design questions rather than afterthoughts [23].

Limitations and Boundary Conditions

Several qualifications should be highlighted. As a conceptual contribution, the model of course awaits empirical validation; because it has not yet been tested, its propositions should be read as hypotheses to be examined rather than as established findings, and the magnitude of each path and the relative weight of the five domains remain open empirical questions. The model is deliberately parsimonious, and simplicity has limitations: by folding mechanisms such as digital self-efficacy, explainability, and participatory design into broader domains, it sacrifices some of the detail that a more complex framework would offer. The domains are also analytically distinct but empirically correlated: contextual fit, for instance, raises both perceived value and usability. The framework is oriented toward low-resource and smallholder contexts and may require adaptation for commercial or highly mechanized agriculture. Finally, the model treats the farmer as the primary unit of analysis; where decisions are made jointly within households or cooperatives, a collective extension of the model may be warranted.

8. Practical Implications

The model offers concrete guidance. For designers, it suggests prioritizing local-language and low-literacy interfaces; offline functionality; clear, explainable recommendations; visual, audio, and icon-based guidance; participatory testing with farmers; alignment with local crop calendars and practices; visible trust signals, including transparency about information sources; integration with extension workers and farmer groups; and ethical data practices around consent, ownership, and fairness.

For governments, non-governmental organizations, and agritech firms, the model suggests treating applications as complements to human advisory systems rather than as replacements for them. The most effective arrangement is likely to be blended: digital tools provide reach and timeliness, while human intermediaries provide interpretation, trust, and contextual judgment. Investment in connectivity, affordable data, and device access remains a precondition for any of the design gains to be realized, since contextual constraints can nullify even excellent applications.

9. Conclusions

Mobile agricultural applications are not merely information delivery tools. They are human-computer interaction systems embedded in rural livelihoods, institutions, markets,

and ecological uncertainty. Whether they are adopted, sustained, and consequential depends on the perceived agronomic value they offer, their inclusive usability, their contextual and cultural fit, the trust and transparency they afford, and their embeddedness in social and institutional networks. All these are conditioned by the infrastructural and personal circumstances of farmers.

By integrating technology adoption theory, diffusion theory, socio-technical systems thinking, and mobile HCI and HCI4D, this paper offers a parsimonious and testable model for explaining and improving mobile application use in agriculture. Its five domains and six propositions provide a structured basis for survey-based, qualitative, and design-science research, and a practical framework for designing applications that are not only technically functional but also usable, trusted, inclusive, locally meaningful, and capable of supporting farmer empowerment. Because the model has not yet been empirically tested, these propositions are offered as hypotheses rather than findings. The next step is empirical: to test the propositions across diverse crops, regions, and user groups, and to build and evaluate applications that embody the field-ready HCI the model describes.

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Abbreviations

The following abbreviations are used in this manuscript:

Abbreviation	Definition
AI	Artificial intelligence
HCI	Human–computer interaction
HCI4D	Human–computer interaction for development
ICT	Information and communication technology
ICT4Ag	Information and communication technologies for agriculture
TAM	Technology acceptance model
UTAUT	Unified theory of acceptance and use of technology

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