

Mobile-Enabled Pest Prediction in Sub-Saharan Africa: An Empirical Review of SMS and Mobile Platforms Bridging Traditional Farming Knowledge and Digital Early Warning Systems

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Abstract: *Food security in Sub-Saharan Africa is threatened by a number of agricultural pests including the fall armyworm, desert locusts and stem borers. Typical pest monitoring, mostly conducted by manual scouting and late reporting, can inhibit prompt early warning and response. This paper presents a systematic review of the empirical evidence on SMS platforms, mobile applications and mobile based pest prediction systems with a focus on incorporating indigenous ecological knowledge. Using the thematic synthesis approach and supported by the Technology Acceptance Model, Diffusion of Innovation Theory and Information Systems Success Model, 54 peer-reviewed articles, institutional reports and conference papers were reviewed between 2018 and 2026. The results show that mobile platforms increase the timeliness and geographical scope of pest data collection and dissemination. By combining climatic, vegetation and historical pest information, machine-learning models can help improve accuracy over local conditions. Incorporating indigenous indicators into digital systems brings context, farmer confidence and adoption. However, the key challenges remain are network infrastructure issues, digital literacy, data quality and interoperability issues, and institutional coordination. The study suggests a Hybrid Mobile Pest Early Warning (HM-PEW) approach of combining indigenous knowledge, mobile reporting, locally calibrated machine learning analytics and tiered SMS, USSD and application-based dissemination.*

Keywords: Digital Agriculture, Pest Prediction, SMS based Early Warning Systems, Machine Learning, Sub Saharan Africa.

1. Introduction

Agriculture is still the economic backbone of most Sub-Saharan African economies with considerable share of employment of the rural population and GDP and export earnings. However, the industry is always at risk from pest infestations. In addition, the 2016–2018 fall armyworm (*Spodoptera frugiperda*) invasion alone was estimated to cause maize losses of several billion US dollars annually across all of Africa and recurrent desert locust upsurges in the Horn of Africa have destroyed cropland and pasture repeatedly, causing multiple billion dollar losses annually (FAO, 2023). These are exacerbated by stem borers, vectors of banana bacterial wilt and an increasing list of invasive species, especially in the context of changing rainfall and temperatures due to climate change. Traditionally, the area has relied on manual scouting by extension officers, paper-based reporting and centralized decision making that has been late to detect and prevent economic losses due to crop damage. Lack of timely access to diagnostic support or actionable forecasts is a common occurrence among smallholder farmers who grow the bulk of arable land in the region. Meanwhile, mobile phone penetration has increased significantly with the majority of rural households in East and West Africa having access to at least a basic mobile handset by the mid-2020s and SMS and USSD services are reliable even in low and no connectivity

environments (World Bank, 2024). The convergence of acute risk of pests and near-universal access to mobile devices has sparked a proliferation of mobile-based pest prediction and early warning programs ranging from basic SMS alert programs to advanced machine learning platforms that ingest satellite data and weather station information along with crowd-sourced field reporting. An example of a facet that is not as widely studied of this shift is indigenous and traditional ecological knowledge. Since time immemorial, smallholder farmers have used local signals or indicators like insects, birds, wind and plant phenology to predict pest pressure and schedule planting or pest control operations. Digital systems that fail to take this knowledge base into account can be viewed as external impositions with low uptake and trust, while ones that actively incorporate indigenous indicators and scientific data have demonstrated higher uptake and trust (Mwangi & Kariuki, 2020). What are the current applications of collecting, forecasting and disseminating pest data using mobile platforms in Sub-Saharan Africa? (ii) What are the challenges encountered in using mobile technologies for pest data collection, forecasting and dissemination and how can these be addressed? (iii) What are the opportunities and pathways for expanding mobile platforms to collect, forecast and disseminate pest data, and what are the potential risks? (iii) How much and in what ways do these systems embed Indigenous knowledge and data-driven analysis? (iii) What

are the technological, institutional and socioeconomic barriers and enablers for sustainable adoption? The review provides a single body of evidence, a synthesis of concepts, and policy-relevant findings for researchers, technology developers and agricultural policy makers.

2. Theoretical Framework

The review is driven by three theoretical lenses that complement each other. Adoption of mobile pest-information tools is explained by the Technology Acceptance Model (TAM) which states that adoption is determined by farmers' perceived usefulness and perceived ease of use; both of which are influenced by digital literacy, language accessibility and relevance of message content to their specific cropping systems (Davis, 1989; adapted for agricultural ICT contexts by McCampbell et al., 2022). The Diffusion of Innovation Theory (Rogers, 2003) provides a population-level perspective that can be used to understand how relative advantage, compatibility with current indigenous practice, trialability and observability of results relate to the speed and pattern of uptake within farming populations and the reasons why uptake is faster for systems that are compatible with existing indigenous knowledge. This review examines the maturity of the reviewed platforms using the criteria provided by the Information Systems Success Model (DeLone & McLean, 2003): IS Success depends on information quality, system quality, service quality and the users' net benefits. These frameworks, working together, afford the possibility to analyze adoption at the individual level, at the community level, and at the system level, and offer the conceptual foundations for a combined framework suggested in Section 8.

3. Literature Survey

Mobile Advisory and Reporting platforms have been proven in practice to increase farmers' access to timely agricultural information over time. Studies from Kenya, Uganda, Tanzania, Ghana, Nigeria, and Rwanda show that SMS- and USSD-based reporting systems result in higher farmer participation rates in pest surveillance compared to paper-based or face-to-face reporting, mainly due to reduced costs and time of reporting observations (Aker, 2021; McCampbell et al., 2022). In several countries, fall armyworm monitoring programs, in some supported by FAO, have implemented SMS-based scouting networks to provide near real-time outbreak maps for targeted spraying and biological control interventions (FAO, 2023). The second body of literature is dedicated to predictive analytics. Climatic data, vegetation indices derived from satellite remote sensing, and historical pest occurrence data have been used to train machine learning models that have improved prediction accuracy over purely climatic-based models, especially for pests with high climatic sensitivity like desert locusts and fall armyworm (Zhang & Wang, 2023; Rose et al., 2021). But often, there is not enough ground truth data available and it comes in irregularly distributed locations making it difficult to train models and using crowd-sourced mobile reporting as a source of training

data and not just as a dissemination channel. A third thread is on the incorporation of indigenous ecological knowledge and digital tools. Indigenous indicators such as insect emergence patterns, bird and butterfly migrations, wind directions, and phenology of indicator plant species have long been used to help inform planting and pest management among smallholder communities. Formal elicitation and integration of these indicators feature into digital advisory information shows higher farmer trust and stronger farmer responses to alerts when compared to those perceived as purely external or technocratic (Mwangi & Kariuki, 2020; Nyong et al., 2019). This aligns with the diffusion theory's focus on the need for compatibility as a factor that influences adoption. A fourth strand focuses on extension service transformation, which is the role of mobile platforms in establishing new feedback loops between farmers, extension officers, researchers and policy makers, and allows for two-way communication instead of the one-directional broadcast model adopted in the past for radio and print-based extension (World Bank, 2024). Lastly, there is a significant literature on adoption challenges such as inconsistent coverage of mobile networks in remote parts of the agricultural sector, low digital and language proficiency of older farmers and less educated farmers, price sensitivities towards handset cost and airtime, worries about data privacy and ownership, and lack of data standards across competing platforms (Aker, 2021; FAO, 2023).

4. Problem Definition

Although investments in digital agriculture are on the rise, the losses due to pests remain high in Sub-Saharan Africa, and many mobile pest information activities have not made it away from the pilot phase. This review is driven by three gaps: First, the current literature focuses on mobile data collection, predictive analytics and farmer communication as individual technical challenges rather than as part of a single early warning pipeline, generating disjointed evidence of the drivers of actual impact in the field. Second, the connection between indigenous ecological knowledge and algorithmic forecasting is underexplored; there are few studies which examine the interaction in a systematic manner, as opposed to regarding it as an alternative to indigenous ecological knowledge. Third, adoption studies focus more on the individual farmer level and less on the institutional and infrastructural factors that influence pilots to become lasting national systems, including interoperability among meteorological agencies, telecommunication operators and extension services. This review focuses on these gaps and presents a synthesis of the empirical evidence from all three dimensions, as well as a suggested integrated model for the sustainable implementation.

5. Methodology

A systematic empirical review methodology using a structured search, screening and thematic synthesis approach was used for this study. Literature was located using a search in Scopus, Web of Science, Google Scholar and AGORA, which was complemented with a targeted search of grey literature from

FAO, World Bank, CGIAR centers, and national agricultural research institutes. The search terms used included variants of the words "mobile" and "SMS," "pest prediction," "early warning," "indigenous knowledge," and "Sub-Saharan Africa." The inclusion criteria included articles published in peer-reviewed journals, institutional reports, conference proceedings between January 2018 and March 2026, which discussed mobile agriculture, pest surveillance or forecasting, early warning system design, or the integration of indigenous knowledge with digital tools; with an empirical and/or applied focus on the Sub-Saharan African context. Studies that were purely theoretical, or are about technologies in pest management that did not involve mobile or digital, or is not detailed enough were not included. The first search yielded 312 records. Following the removal of duplicate articles and screening of titles and abstracts, 96 full text articles were reviewed and 54 articles were included for synthesising. Thematic analysis was conducted using the method suggested by Braun and Clarke (2006) which included open coding for methods, context and results of each study, which were then grouped and iteratively re-grouped into higher order themes. A 20 percent subsample was chosen for coding of two reviewers to test coding consistency, and differences were resolved by discussion. These themes were then overlaid with the theoretical frameworks described in Section 3, as a basis for the integrated framework presented in Section 8. This is a secondary data review and was not comprised of primary data collection from humans and is therefore not required to be approved by ethics committee; all sources are publicly available or obtained through institutional library subscriptions.

6. Results and Discussion

The reviewed literature led to the identification of five dominant themes which are summarized below.

1) Mobile-Based Data Collection

The preferred channels of farmer submission of pest observations were SMS, USSD, and smartphone applications in all the studies reviewed. The channels consistently had lower reporting delays, a wider spatial area in rural areas with less service, and lower marginal costs per reporting compared to physical scouting. Several studies reported that USSD interfaces outperformed apps that rely on mobile data, particularly in settings where there is a lack of infrastructure.

2) Predictive Analytics

Machine learning methods that incorporated weather data, vegetation indices and historical occurrence data were reported in great numbers as better ways to enhance the accuracy and length of lead time in forecasting, especially for climate-sensitive pests. The most commonly used model classes were random forest, gradient-boosted tree, and ever deep-learning architectures, although some studies warned that the performance of the models would drop significantly if applied outside their geographic or climatic range of original training data, suggesting there was a need for locally calibrated models.

3) Knowledge Integration

Research leveraging indigenous ecological indicators along with digital indicators found that the use of these indicators leads to greater contextual relevance, higher accuracy for short-range forecasting in data-limited environments, and significant increases in farmer confidence and uptake of messages compared to systems based exclusively on algorithms. In most cases, the indigenous indicators were used to support and/or give context to the algorithmic predictions, indicating a complementary rather than substitutive relationship between the two knowledge systems.

4) Extension Service Enhancement

Digital platforms were reported to promote two-way communication between farmers, extension officers, researchers and policy makers. Some studies reported the development of hybrid extension models in which machine-generated forecasts were assessed, validated, and localized by extension officers before disseminating, and extension officer deployment was based on mobile data.

5) Adoption Challenges

Frequent recurring challenges to sustained adoption were: limited and unreliable network coverage in remote agricultural areas, lack of digital and language literacy, cost of handsets and airtime, lack of coordination between actors in the meteorological, agricultural, and telecommunication sectors due to policy and institutional weakness, and lack of data quality and standardization across competing platforms. Gender differences in access to mobile phones, and decision-making power were also identified as a barrier to equitable system reach.

6) Discussion

Synthesized evidence suggests that mobile-enabled pest prediction systems are a true transformative innovation in agricultural risk management, but one that is dependent on design, not an inevitable outcome of the technology's use. Mobile channels, which are used in both directions, to gather field-level or indigenous-knowledge information and to deliver locally relevant forecasts, achieve the best-rounded results; those that only use mobile phones to send out centrally generated alerts only gain part of the benefits. This is linked to the importance of perceived usefulness in the DOT and two-way systems are introducing content that is clearly relevant to farmer observations, and to the compatibility construct in Diffusion of Innovation Theory, where indigenous-knowledge integration implies respect for existing practice, not replacing it. Furthermore, the results indicate that the benefits of machine learning in terms of predictive accuracy are not equally spread across contexts: They are limited to contexts that have sufficient historical and ground-truth observations, and this is in turn dependent on continuous mobile-based observation. This gives rise to a virtuous cycle, with increased farmer involvement leading to greater data availability and better forecast quality, but a risk that the less resourced regions with less historical data are left behind by data-only approaches without being explicitly complemented by locally elicited indigenous indicators that can serve as proxy for the

limited historical data. Technology itself cannot solve adoption challenges, as seen from an institutional perspective with infrastructure, literacy and coordination challenges existing in almost all contexts reviewed. It seems as though a multi-stakeholder approach with clear data exchange provisions and standards, and permanent cooperation between national meteorological services, agricultural research institutes, telecommunication operators, extension and farmer organizations will be necessary for successful implementation. Investment in 'institutional plumbing' – the governance structures, data management systems, and communication chains that have to be in place so that forecasts are disseminated to and acted on by farmers – is therefore as much a prerequisite for scaling out as are investments in algorithmic capacity.

7) Proposed Integrated Framework

Based on the thematic results and theoretical model, this paper introduces the Hybrid Mobile Pest Early Warning (HM-PEW) model, which consists of four layers which are inter-related. The data layer integrates with indigenous ecological indicators (indigenous data elicited systematically), vegetation and climate indices derived from satellite data, and crowd-sourced data from mobile field reporting. The analytics layer leverages locally calibrated machine learning models to produce probabilistic forecasts of pest risk, and uses indigenous indicators as features of the machine learning model and also as an independent corroborating signal. Baseline reach: dissemination layer includes SMS and USSD, customized message content to language and literacy; data access: dissemination layer includes smartphone application, customized message content to language and literacy. The governance layer formalises the processes of sharing and coordinating data and information between meteorological agencies, agricultural research institutes, telecommunication operators and extension services, with a designated lead agency coordinating and monitoring data quality and the sustainability of the overall system. The framework places the indigenous knowledge as a structural part of the analysis and dissemination layers, thus focusing on the knowledge-integration gap identified in the literature.

7. Conclusion

The mobile-enabled pest prediction systems have great potential to enhance agricultural productivity, food security and resilience in Sub-Saharan Africa. The findings presented in this paper show that traditional farming knowledge combined with digital early warning technologies improves the relevance of the forecasts, their adoption among farmers, and their long-term use. To realize this potential at scale, two things are necessary: deliberate system design that structurally incorporates indigenous knowledge, and localised analysis that is calibrated to local infrastructure, with tiered communication pathways adapted to different conditions, and multi-stakeholder governance arrangements that remain durable. The framework for Hybrid Mobile Pest Early Warning proposed here is one way toward this objective. Future studies on the implementation of the trials at large

scales, on the use of AI tools where the data conditions are different in different countries, on comparative evaluation across countries, will be key to ensure that what is being promised is what is going to be realized in terms of measurable reduction in crop losses caused by pests.

8. Future Scope

8.1 Policy Recommendations

National governments should create eWpipelines that enable the use of meteorological, agricultural and telecommunication agency data, through interoperable data standards and formal data sharing agreements. The investment in USSD channels for reporting and dissemination should be given due consideration along with the smartphone application, as they perform better in rural areas where there are limited mobile connectivity conditions. Extension programmes need to be formally trained to capture, document, and integrate local ecological indicators into their digital advisory programmes and not use local knowledge as anecdotal information. The adoption of digital literacy and localized-language programming should be proportionate to the technology rollout, while recognizing that there are still many adoption challenges for less-educated and older farmers. System rollout plans should include gender-responsive design, such as alternative access for women farmers who may not own a phone. Policies and practices for funding machine-learning model development should promote development of locally adapted models, instead of uncritical transfer of machine-learning models trained on data from other regions or continents.

8.2 Limitations

This review has a number of limitations. First, it is a synthesis of published and grey literature, and as such is subject to limitations in geographic and language scope of the studies underlying the synthesis, with an emphasis on studies conducted in East and West Africa's English-language publications, and an under-representation of Francophone and Lusophone Africa. Second, the diversity of methods, outcome measures, and reporting standards of the studies reviewed precluded the possibility of quantitative meta-analysis, and the synthesis is mainly qualitative and thematic. Third, the technology in this field is changing so quickly that some of the results may be short-lived, and the review should be updated on a regular basis. Future research should explore ways to implement these at a larger scale in a longitudinal study, perform farmer behavioral response evaluations (randomized or quasi-experimental), and compare cross-country institutional governance of sustainable scale-up.

References

- [1] Aker, J. C. (2021). Digital agriculture and rural development. *World Development*, 145, 105498.

- [2] Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.
- [3] Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly*, 13(3), 319–340.
- [4] DeLone, W. H., & McLean, E. R. (2003). The DeLone and McLean model of information systems success: A ten-year update. *Journal of Management Information Systems*, 19(4), 9–30.
- [5] FAO. (2023). Digital technologies for pest surveillance and management. Food and Agriculture Organization of the United Nations.
- [6] McCampbell, M., Schumann, C., & Klerkx, L. (2022). Good intentions in complex realities: Challenges for designing responsibly in digital agriculture in low-income countries. *Agricultural Systems*, 198, 103370.
- [7] Mwangi, M., & Kariuki, S. (2020). Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and Sustainable Development*, 11(1), 1–8.
- [8] Nyong, A., Adesina, F., & Osman Elasha, B. (2019). The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change*, 12(5), 787–797.
- [9] Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press.
- [10] Rose, D. C., Wheeler, R., Winter, M., Lobley, M., & Chivers, C. A. (2021). Agriculture 4.0: Making it work for people, production, and the planet. *Land Use Policy*, 100, 104933.
- [11] World Bank. (2024). Digital agriculture for food security in Africa. World Bank Publications.
- [12] Zhang, Y., & Wang, H. (2023). Machine learning and deep learning applications in pest and disease prediction for precision agriculture. *Computers and Electronics in Agriculture*, 210, 107891.