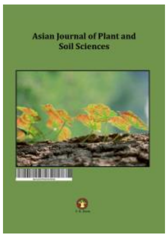

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The Role of Digital Technologies in Advancing Plant Pathology in Africa

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Diagnosing plant diseases is a complex process that blends science and intuition. The integration of digital technologies, including machine learning, AI, and mobile applications, offers significant opportunities for plant pathology research and practice in Africa. These tools enable the efficient processing of large datasets, timely disease diagnosis, and precision agriculture, enhancing productivity and food security. The use of digital technologies to enhance data analysis methodologies presents a huge opportunity for African plant pathology research. this contains details about managing livestock, access to finance facilities, market availability and produce pricing, precision farming and irrigation, pest and disease control, and extension services. However, challenges such as limited access to technology and digital literacy persist. This study explores current advancements, challenges, and the potential of digital tools to transform plant pathology in Africa, paving the way for innovative, sustainable agricultural practices.

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Importance of the work:

- The work shows how digital instruments can be used to treat plant diseases.
- IT also shows the developments in imaging tools and analysis approaches to provide an overview of the state of digital plant pathology research at the moment in Africa.

Objectives:

1. To examine how digital instruments are used to treat plant diseases.
2. To offer a possible new avenue for African research in digital plant pathology.

Keywords: Digital; plant pathology; modern; Africa; contributions.

1. INTRODUCTION

The diagnosis of plant diseases is a complex procedure that blends science and art (Gerald et al., 2000; Grogan, 1981). Scientific methods are used in conjunction with ocular observation and intuitive judgment to identify the symptoms and indicators of plant diseases. According to Dyson (Dyson, 1999) the use of photographic pictures that show the symptoms and indicators of plant diseases has become essential in many areas of plant disease research, education, extension, and diagnosis. Holmes (Holmes, 1999) found that the rapid sharing of high-resolution digital photos across numerous sites was made possible by developments in modern telecommunications.

Holmes et al. (2000) demonstrated that this capacity created new avenues for the integration of digital imaging and image transfer techniques into the diagnosis of plant diseases, facilitating remote consultations and enhancing precision. As mentioned by Okigbo and Ogbonnaya (2006) the continuous use of chemicals to treat yam diseases resulted in the target organisms developing resistance; this is frequently the case with the introduction of new techniques or changes in protocols. Nevertheless, the adoption and implementation of these digital tools have not been without controversy. Globally, digital technology has revolutionized many fields, and modern plant pathology holds great promise for the advancement of African agriculture. Digital tools have become increasingly important in plant pathology in Africa, providing fresh ways to improve disease diagnosis, treatment, and detection across the continent. Plant disease research, monitoring, and control could be completely transformed by digital tools thanks to developments in data processing, imaging, and communication technology. These tools would also help to solve the particular problems that African agriculture faces. The advancement of plant pathology research in Africa has been made possible by the incorporation of digital imagery and analysis. High-resolution digital photos of the symptoms and indicators of plant diseases, according to Dyson (1999) offer essential visual documentation and help with precise disease identification and characterisation. Because these photos are easily shared, researchers, diagnosticians, and extension professionals from different geographical places can work together more easily.

In environments with limited resources, digital imaging methods like smartphone-based photography provide an accessible and affordable method for documenting diseases. The necessity for sustainable agriculture was recognized by Davies and Shen in (2020) as a result of changing public perceptions of the environment that have forced farmers to reevaluate their methods, particularly plant protection tactics. Since agriculture takes up a large amount of the land that is accessible, the problem is how to maintain the environment while producing enough food to feed the world's expanding population (Food and Agriculture Organization of the United Nations, 2018; 2021). The use of digital technologies to enhance data analysis methodologies presents a huge opportunity for African plant pathology research.

Large datasets may be processed and interpreted accurately and efficiently with the use of computer algorithms, machine learning, and artificial intelligence (Matheus et al., 2022). These cutting-edge analytical methods are capable of identifying disease trends, forecasting outbreaks, and optimizing African-specific disease control plans. Digital tools can offer important insights to researchers, policymakers, and farmers by analyzing data from various sources, such as weather patterns, crop performance, and disease occurrence. For the purpose of monitoring plant diseases in Africa, digital tools combined with remote sensing technologies have a number of advantages.

Silva et al. found in (Silva et al., 2021) that drone-based surveys, aerial photography, and satellite imaging offered a thorough picture of crop fields, facilitating the detection and evaluation of disease incidence and severity. When paired with digital image analysis and machine learning algorithms, remote sensing data can help identify diseases early, enable focused interventions, and make the most use of scarce resources in African agriculture. Integrated pest management (IPM) has been shown to be effective in lowering harvest losses caused by pests and plant diseases, but tracking and identifying illnesses across vast agricultural areas is still difficult, according to Savary et al. (Savary et al., 2019).

Plant diseases can be monitored in both space and time with high precision through the use of non-contact optical sensors in the field of remote sensing (Mahlein, 2016). The field of remote sensing offers non-destructive disease monitoring approaches that maximize disease detection efforts through the utilization of diverse optical sensors, including RGB (Red, Green, Blue), multi- and hyperspectral, thermal, chlorophyll fluorescence, and 3D-imagin (Silva et al., 2021). For the purpose of spreading knowledge about plant pathology throughout Africa, digital platforms and knowledge-sharing mechanisms are essential. Opportunities to exchange disease information, diagnostic procedures, and research discoveries are provided via online databases, digital libraries, and web-based platforms (Gerald et al., 2000).

These platforms facilitate the dissemination of current knowledge, encourage cooperation between African practitioners and researchers, and encourage the adoption of disease management strategies that are appropriate for the specific conditions of each region. Even with such great promise, there are still obstacles in the way of fully utilizing digital tools in African plant pathology. According to Matheus et al. (2022). barriers to universal adoption of technology included unequal access to it, poor infrastructure, and differences in digital literacy. In African agricultural communities, efforts must be taken to guarantee that digital technologies are affordable and accessible, to foster capacity building, and to bridge the digital gap. Furthermore, there are additional challenges involved in applying remote sensing techniques for plant disease diagnosis.

Matheus et al. (2022) reported that plant diseases exhibit variability within crop stands and dynamic geographical and temporal patterns, which are impacted by living organism interactions and constantly changing environmental conditions. Poor infrastructure, such as impassable roads, spotty energy connections, and spotty Internet connectivity, is a common feature of rural Africa. Crop pest surveillance and control, according to Sine et al. (2010) is a difficult but necessary work because of this, poor literacy rates, and the aging population that makes up the majority of farmers in rural communities.

Moreover, farming in rural communities is an unsatisfactory endeavor due to additional problems such language hurdles and limited access to timely and pertinent information on pest identification, control, and prevention (Togola et al., 2018). But given that mobile phones are becoming more and more common in these communities, we contend that we can use the majority of farmers who own these phones to help with pest surveillance by using a crowdsourcing platform powered by mobile phones. Given this, digital plant pathology has to put farmers' interests first while utilizing the latest developments in imaging and processing techniques to maximize disease identification (Matheus et al., 2022).

The huge output reductions caused by plant diseases have a significant influence on global agriculture, which emphasizes the significance of early identification and precise diagnosis (Strange & Scott, 2005). Successful identification of the causal agents is crucial for disease control strategies, and erroneous diagnosis can result in resource waste and higher plant losses (Strange & Scott, 2005; Kumar & Sreenivasulu, 2009). Effective disease management, such as the use of plant extracts to treat human diarrhea (Okigbo & Ezeaku, 2018; Afam-Ezeaku et al., 2022). preventing the establishment and spread of pests and pathogens, and minimizing their impact, depends on proper disease diagnosis and early detection (Okigbo & Uwah, 2022; Anukwuorji et al., 2021).

Digital tools' application to contemporary plant pathology in Africa has enormous potential for the advancement of sustainable agricultural growth. Innovative strategies for disease diagnosis, monitoring, and management are provided by digital imaging, data processing, and remote sensing technologies, which are specifically designed to address the distinct obstacles encountered by African farmers. Effective disease management techniques are adopted through teamwork and the use of digital platforms for knowledge exchange. African plant pathologists can enhance crop health, boost agricultural output, and promote food security on the continent by utilizing digital tools. In addition to offering insights into the level of digital plant pathology research today, this study attempts to assess the use of digital tools in the context of plant disease management. The study also looks at the developments in imaging tools and analysis approaches to provide an overview of the state of digital plant pathology research at the moment.

e-Pest Surveillance: Comprehensive Crop Pest Monitoring and Management Major agricultural pests have increased in Africa, as Table 1 illustrates.

Nonetheless, Sub-Saharan Africa has seen a notable rise in the use of mobile phones in recent years. According to Awuor et al. (2016) the GSMA1 report indicates that as of 2017, 44% of people in Sub-Saharan Africa were using mobile phones. By 2025, that percentage is expected to rise to at least 52%. This can be ascribed to the region's recent experiences with flexible browsing bundle packages and reasonable mobile phone calling costs. Notably, consumers now have more power thanks to mobile phone connectivity, which is also greatly boosting economic growth. Users can now access the majority of necessary services, such as utilities, health and education services, financial services and credit facilities, and utilities, through their mobile phones (Tadesse & Bahiigwa, 2015). Offering these mobile customers mobile-based services that are tailored and context-aware presents enormous opportunity. Therefore, mobile-based device technology has been used to provide farmers in Sub-Saharan Africa with timely, accurate, and consumable agricultural information ranging from farm preparation to pre-harvest and post-harvest crop and farm produce management, in an effort to ensure food security and increase agricultural productivity. Table 2 lists the following information: market availability and produce pricing; pest and disease control; digital devices or tools that can be used; locations where they have been used; irrigation and precision farming; access to credit facilities; and extension services, among other services like livestock management and associated benefits and drawbacks.

Farmers need information on current farming practices and procedures that can boost their farm yields desperately because of the changing climate and unpredictable and inconsistent rain patterns that necessitate the adoption of new crop varieties and farming abilities. This demonstrates how important it is for farmers to have access to agricultural information, which is extremely expensive in Sub-Saharan Africa (Tadesse & Bahiigwa, 2015), in order for them to make decisions. FAO (2018) uses market prices that are widely available on mobile devices to show how such information could help smallholder farmers determine more appropriate prices for their produce.

In order to showcase their produce to buyers and brokers, farmers should avoid making repeated trips to the market and loading and unloading at the market.

One such service is SokoniSMS64 (Tata & McNamara, 2018) which gives Kenyan farmers access to market rates for their produce across the nation. Kenya offers a number of mobile-based agricultural services, such as CocoaLink, iCow, and Kilimo-Salama. In Kenya, farmers are protected against unfavorable weather circumstances via Kilimo-Salama, a micro-insurance mobile-based "pay as you plant" type of insurance plan (Awuor & Rambim, 2014).

Like Tigo-Kilimo in Tanzania, it also offers real-time meteorological information to help farmers manage their farming. However, iCow3, a mobile phone-based application, helps farmers monitor several aspects of their cows' gestation, such as the kinds and timing of their feed, local veterinary contact details, and exact cattle market pricing. Awuor and Rambim (2018) claim that the Cocoa Link is a free mobile solution based on text and voice messages that offers farmers in Ghana information on crop disease prevention, crop marketing, and best farming methods in both native and English languages.

It is noteworthy that most farmers are unable to find pertinent and accurate just-in-time information, despite the fact that they are increasingly using their mobile phones to search for information (Tadesse & Bahiigwa, 2015). This is because the majority of farmers are aware of the vast agricultural resources that are available to them via these devices. The majority of the time, the farmers do not receive timely information in an easily readable format. The fact that the majority of the materials are offered in English and the majority of these farmers being illiterate in addition to not being able to speak or understand the language contributes to this in part.

The majority of these African rural farmers also have rudimentary feature phones that do not handle multimedia, which is how most content is delivered. This is the second reason. Furthermore, farmers frequently access a large amount of stuff via the internet and mobile devices, some of which might be challenging to verify and authenticate. This could contribute to the well-known issue of information overload. In order to provide farmers with agricultural information in a format they can access and use, farmer-centered Agricultural Information Systems (AIS) are required.

Even while AIS can be a web-based or mobile application, its design must always prioritize giving farmers a distinctive and fulfilling experience by giving them the information they require and making it simple to use. This suggests that AIS must offer farmers easily assimilated formats containing timely, pertinent, and reliable information. This is why the majority of AISs (Agricultural Information Systems) are currently offered to farmers in their native tongues and include call center representatives that farmers can reach at any time to answer questions in their native tongues.

Additionally, AIS employs voice assistants, who allow farmers who are incapable of writing or reading to communicate with the organization and receive individualized support in their mother tongues. Moreover, the AIS (Agricultural Information System) has supported farmers using entry-level feature phones by using SMS and USSD. A comprehensive analysis of AIS design, encompassing pull-and push-based designs, collaborative and participatory design, may be found in Awuor et al., (2016). Many AIS applications that are context-specific and tailored to farmers' needs can now be developed because to advancements in mobile technology and the pervasiveness of mobile phones.

The Agricultural Information System (AIS) is now able to offer farmers comprehensive and integrated digital solutions to meet their needs by utilizing a variety of sensors found in smartphones as well as technologies like cloud computing and Internet of Things, data mining

Table 1. The hypothetical increase in major crop pests in Africa

S/N	Pest Name	Region	Crops Affected	Estimated Increase in Pest Incidents (2010-2020)	Source
1	Fall Armyworm	Sub-Saharan Africa	Maize, Sorghum, Millet	300% increase	FAO, (2021)
2	Desert Locust	East Africa, Horn of Africa	Various crops	250% increase	FAO, (2021)
3	Cassava Mosaic Virus	West and Central Africa	Cassava	150% increase	IFAD, (2020)
4	Banana Xanthomonas Wilt	East Africa	Banana	200% increase	CABI, (2021)

Table 2. The changes in pest control efficiency or crop yield before and after implementing e-Pest surveillance technologies

Tool/Technology	Description	Application in Pest Surveillance	Examples of Use in Africa	Advantages and Limitations
Remote Sensing	Use of satellite imagery to monitor crop health	Identifying pest hotspots	Used in Kenya for maize	Provides broad area coverage; may have resolution issues
Mobile Apps	Smartphone applications for pest reporting	Real-time data collection	App-based surveys in Uganda	Accessible, real-time data; Requires smartphone access
Drones	Unmanned aerial vehicles for crop monitoring	Detailed pest distribution mapping	Drones used in South Africa	High-resolution images; Costly and requires training
AI and Machine Learning	Algorithms for analyzing pest data	Predictive analytics and pattern recognition	Used in Nigeria for forecasting	Can predict pest outbreaks; Requires large datasets

Source: (Mohanraj et al.*, 2016)*

and analytics, participatory sensing and crowdsourcing, remote sensing, online content, and social media, among others. This strategy can be used to find solutions for some of the vexing issues that farmers are currently facing. For example, in low-income nations like Kenya, it can help farmers prevent disease inversion and be proactive in dealing with crop and animal pests. It can also be used to conduct extensive pest and disease surveillance in these nations.

2. THE ROLE OF DIGITAL IN CONTROLLING FALL-ARMY WORM IN AFRICA

Plant health and high-quality plant products are essential for both farmers and consumers. With growing knowledge of plant ecology and pest control, initiatives to enhance plant health have changed. Despite being effective in reducing crop pests, pesticides have a negative impact on the environment and public health (Luvisi, 2016). Pesticide residues in food crops have frequently been found to above permissible thresholds. Certain agricultural pests, like Fall-Army Warm (FAW), have developed a resistance to insecticides, and there is now no known effective treatment for them.

However, as Table 3 illustrates, agricultural pests can be managed and their effects reduced by regularly searching and keeping an eye out for them on the farm. Crop pest surveillance is the term used by Sharma et al. (2024) to describe this technique.

To be clear, the term "crop pest surveillance" in this work refers to the continuous monitoring and scouting of pest population dynamics, incidence, and crop damage in order to alert farmers to the need for prompt and effective crop protection measures.

For the purpose of illustration, FAW control is used to gauge how well the suggested framework performs. FAW is an invasive crop pest that is quickly expanding throughout Sub-Saharan Africa, endangering food security and possibly exacerbating world hunger and poverty (Abrahams et al., 2017). Agriculture specialists estimate that FAW (Fall-Army Worm) might cost over $13 billion in losses for crops like sugarcane, rice, sorghum, maize, and over 80 other plant species (Bateman et al., 2018). It can also travel up to 1,600 kilometers (about 1,000 miles) in less than 30 hours, which allows it to move quickly and easily to other farms and nations.

Table 3. Effects of crop pest surveillance in the field

S/N	Effect Area	Description	Examples	Citation
1	Improved Pest Management	Enhanced ability to detect and manage pest outbreaks through timely and accurate information.	Early detection of Fall Armyworm leading to targeted pesticide application.	FAO, (2021)
2	Economic Benefits	Reduction in crop loss and improved yield due to effective pest control measures.	Increased maize yield in Kenya due to early pest detection and control measures.	World Bank, (2020)
3	Environmental Impact	Reduced environmental damage by optimizing the use of pesticides and promoting sustainable practices.	Lower pesticide usage due to precision application methods and reduced pesticide runoff.	CABI, (2021)
4	Public Health	Decrease in health risks associated with pesticide exposure due to reduced or more targeted pesticide use.	Reduction in pesticide-related health issues among agricultural workers.	EPA, 2021
5	Data-Driven Decision Making	Better strategic planning and resource allocation based on accurate and timely pest data.	Use of pest surveillance data to inform crop rotation and pest management strategies.	FAO, (2020)

Transnational actions are required due to the extent and velocity of the FAW outbreak. It is imperative that smallholder farmers and others who assist them receive information on how to combat and prevent the pest as soon as possible. Improved access to timely, accurate, and useful information on how to detect, mitigate, and combat the Fall Army-Worm (FAW) is necessary for smallholder farmers in order to stop the spread of the disease and lower the likelihood of another humanitarian disaster. Digital technologies that are becoming more widely available, such as sensors, geospatial imagery, and data analytics, can be used to help smallholder farmers make decisions by giving them helpful recommendations (Bateman et al., 2018).

In order to help farmers efficiently combat FAW invasion, the idea of Digicult, an e-pest monitoring digital platform, was put forth. Digicult uses crowdsourcing, image processing, and a mobile device. Digicult offers farmers a mobile device-based digital training resource for FAW (Fall Army-Worm) detection and prevention. In order to guarantee that farmers without smartphones can receive trainings through nearby smart farmers—also known as field agents with smartphones—the digital training resource facilitates crowdsourcing. Additionally, Digicult offers a monitoring system to help farmers identify, track, and evaluate FAW outbreaks and hazard levels in their fields and communities. This module gathers routine farmer inspection reports, processes images, and analyzes data to find epidemics and threat levels.

Furthermore, as illustrated in Fig. 1, Digicult offers preventive mechanisms to halt or manage FAW invasion in addition to therapy alternatives for cases where FAW is identified.

In this manner, farmers in the area where Fall Army-Worm (FAW) infestation has been found should be warned to exercise caution, keep an eye out for potential FAW (Fall Army-Worm) incursions on their own farms, and receive recommendations for preventive measures.

Additionally, Digicult gathers, examines, and disseminates information on FAW from the system's interactions with farmers in order to determine the behavior of FAW in the many regions where it has been recorded, thereby assisting in the development of mitigation techniques.

The Digicult platform is a digital tool for extension agents, agro-vet stores, local and regional governments, and other stakeholders working with farmers to prevent FAW, even though it is farmer-centered and focused on enabling farmers to limit FAW and its impacts. In this sense, Digicult consists of three parts: an SMS-USSD service, a mobile application, and a central server (sometimes known as a web application or web-based database). The web-based database, often known as the central server, houses all of the platform-related data. For example, FAW (Fall Army-Worm) outbreak and spread are tracked and visualized using it.

In order to help local farmers with FAW identification and local training, it is also utilized to link them with crowdsourced local field agents. Additionally, the database keeps track of agro-vet information and recommends to farmers local agro-vets who might be stocking chemicals to control FAW. Smart farmers can learn about FAW (detection, control, and prevention) and share important information about FAW (Fall Army-Worm) with their fellow farmers who may lack a smartphone or be illiterate by using the Digicult mobile app4. A light-end image processing module in the application recognizes FAW on the crop automatically.

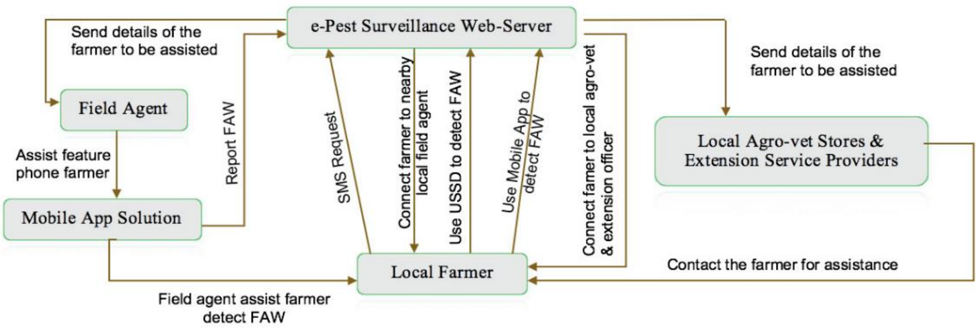

Fig. 1. Mobile phone based pest surveillance for fall army-warm
Source: Bateman et al.*, 2018*

All the farmer has to do is aim the phone's camera at the alleged crop pest, and the app will help her determine whether or not it is a fruit fly (FAW) and provide information on the extent of damage or infection. The smartphone app also offers a geographical mapping, or information visualization, of the FAW infection and spread that has been documented on the platform. It also connects and suggests affected farmers to the closest local extension service providers and agro-vets stores in order to help them. To guarantee that farmers who report FAW cases receive assistance and that all farmers conduct routine FAW checks on their fields, the app includes a follow-up system.

If you don't have a smartphone and can't access the mobile app, you can use the SMS-USSD5 module. The farmers can communicate with the Digicult platform by creating profiles, reporting FAW, and requesting help in their own tongues using a straightforward *384*422# code.

Farmers can use Digicult in four ways: to find nearby and trustworthy agro-vet stores where they can purchase pesticides; to perform a plant infection detection with the image processing assistant and receive recommended treatment; to learn about FAW through the digital training content; and to use the infection report map to track the spread of FAW in the region and nearby areas.
To ensure that farmers receive the most recent, pertinent knowledge on FAW, the digital training materials are designed in close collaboration with FAW experts and updated on a regular basis (Fig. 1).

Best agricultural measures to stop FAW invasions are presented together with information on how to identify and detect FAW invasions. In order to make sure that the farmers can implement the suggested methods, the information is adapted to their locality and written in a language that they can comprehend. With the use of the multimedia-based FAW (Fall Army-Worm) inversion detection tool, farmers may "on-the-fly" identify FAW invasions from photos they took while scouting. In order to provide a treatment plan that works, this technology also determines the crop's stage of FAW invasion.

The treatment proposal makes recommendations for a set of acceptable steps that the farmer may do to resist the invasion by leveraging artificial intelligence to learn from past experiences and FAW specialists on tactics that are appropriate given the farmer's location. If and when FAW has been reported in the farmers' neighborhood, the solution also notifies the farmers to check the farm for FAW. In this manner, farmers are able to identify FAW early on in the disease's progression on their farms. Additionally, farmers have access to approved agro-vet establishments in the area, which are suggested to them for the purchase of pesticides.

Upon their registration, the agro-vet outlets undergo a preliminary evaluation by Digicult, and a customer review system is employed to verify that the level of service provided by these establishments is satisfactory.

3. DISEASE MANAGEMENT IN THE FIELD

Since the early 1990s, weather-based consultation and forecasting systems (such proPlant Expert.com and RANTISMA) have enabled the best plant protection methods for disease management by providing warning services of emerging pests and diseases (Newe et al., 2003). Table 4 lists the many digital techniques that are utilized in Africa to manage agricultural diseases in the field.

Digital consulting systems optimize time management and the procedure for a successful plant protection measure, but the farmer's manual field check is still required (Damos, 2015). Still, a lot of approaches and procedures require a lot of work, therefore more development is required. In his review, Nilsson (1995) came to the conclusion that remote sensing provides a greater variety of sensors and application scales, from satellites to ground-based platforms. However, pre-symptomatic and disease-specific identification, as well as the impact of the environment, continued to be significant challenges, contingent on the size (Mahlein et al., 2012). Based on the observation that plant-microbe interactions result in minute modifications to biochemistry and structure, this is made. Plant pathogenesis and plant resistance response are examples of compatible and incompatible interactions that can be used to characterize the interactions.

4. DIGITALIZATION IN AGRICULTURAL PRACTICE

Researchers have become more confident in using unmanned aerial and ground vehicles after the year 2000 (Fig. 2).

Challenges are to capture and explain the complexity resulting from the triangular relationship of sensor, pathogen, and environment. Implementing new method is hindered by the lack of plant protection and the growing resistances. The analysis of big data is labor-intensive and needs sophisticated data-driven approaches, which can only be sufficiently interpreted by a multidisciplinary team. Currently, the development of agricultural robots, which can detect, assess and operate autonomously, is a research focus and, in the view of weeding, are very promising. Personal consulting is a driving force to introduce new technologies and digital possibilities into agriculture. Thereby, computer/software approaches, as well as smart solutions enable fast and interconnected access to global data.

These might have improved spatial resolution reflectance-based sensors for illness detection, which would enable more accurate differentiation between biotic and abiotic stress. A 3 ha/h work rate was attained by certain systems (West et al., 2003). However, Wegener et al. (2019) found that inconsistencies in illumination intensity, sun/sensor alignment, and/or background soil reflection were preventing reliable and high-quality data recovery. It was discovered that another issue was soil dust, which caused physical harm to the crops through the vehicle and led to identification errors.

Fig. 2. Achievements, challenges, and current research of digital plant pathology for adaption into the field practice

Source: (Matheus et al*., 2022)*

Table 4. Digital technologies in agricultural practices in Africa

S/N	Digital Technology	Description	Applications	Examples	Citation
1	Mobile Apps	Applications on smartphones for real-time information, monitoring, and management of agricultural practices.	Pest and disease identification, weather forecasting, market prices.	PlantVillage app, AgroApp.	Plant Village, (2022)
2	Remote Sensing	Use of satellite imagery and drones to monitor crop health, soil conditions, and environmental factors.	Crop health monitoring, precision farming, yield estimation.	Drones for monitoring cassava, satellites for soil moisture mapping.	FAO, (2021)
3	Geographic Information Systems (GIS)	Tools for analyzing spatial data to support decision-making in agriculture.	Mapping pest and disease outbreaks, land use planning.	GIS mapping of maize and soybean fields in Kenya.	World Bank, (2020)
4	Data Analytics and AI	Machine learning algorithms and data analysis tools to optimize agricultural practices and predict outcomes.	Predictive analytics for crop yields, disease outbreaks.	AI-driven models for predicting Fall Armyworm infestations.	IFAD, (2019)
5	Digital Platforms for Farmer Advisory Services	Online platforms providing farmers with advice, alerts, and market information.	Real-time agricultural advice, market access, weather updates.	e-Choupal, Agro-Innovate.	ICRISAT, (2020)

Automatization, mechatronics, sensors, electrical engineering, and artificial intelligence have advanced to a point where mobile platforms like automobiles, drones, and robots can operate with a high degree of autonomy (Fig. 2). The next digitalization stage in African agriculture is autonomous robots with advanced sensor systems for automated mechanical weeding, precision fertilizing, and pesticide spot-spraying. These robots are used in conjunction with other digital devices, as shown in Table 4.

In fact, automated robotic applications may provide a way around the scarcity of human labor, particularly for labor-intensive jobs like hand weeding or vegetable picking (Lowenberg-DeBoer et al., 2020; Wegener et al., 2019) also pointed out that the use of automated systems changed the way agricultural output was planned, taking into account regional variations in the distribution of plant pests or input parameters like water, fertilizer, and agrochemicals. Depending on the type of crop and cultivation method, many robotic applications for crop management are being developed. Zhan et al. (2021) cite the use of unmanned aerial vehicle (UAV) technology in the field to release *Trichogramma brassicae*, a naturally occurring adversary of *Ostrinia nubilalis*, the European corn borer, as a biological control mechanism for corn plants.

UAVs provide for a quick and efficient application in open terrain as opposed to the labor-intensive manual application of "Trichogramma bags." Higher degrees of automation are currently in place in greenhouses; examples include robotic tomato plant protection measures and pepper harvesting (Arad et al., 2020). The issues associated with field crops vary depending on whether they are grown in rows (such as maize, sugar beet, and cauliflower) or randomly distributed (like cereals). According to Bakker et al. (2010), the selective eradication of weed within and between crop rows employing actuators such as milling heads, lasers, stampers, or mechanical weeding instruments (Achugbu et al., 2022) is becoming an increasingly popular application.

When qualified laborers for manual weeding were unavailable during the COVID-19 epidemic, prototypes of these weeding robots increased public awareness (Mitaritonna & Ragot, 2020). Robotic weeders are developing quickly, especially for row crops. These robots can be outfitted to handle various working concepts and are available for purchase. The first idea relies on the seed pill's extremely precise GPS location. An automated weeding system and orientation require precise sowing with very little mistake. All of the field is weeded by the robots, with the exception of the area surrounding the seed that has been planted. The second idea operates separately from the sowing phase (Campbell, 2009; Gill & McSorley, 2011).

By utilizing digital cameras and a modified vision recognition system that mostly relies on neutral networks together with an extensive training dataset, the robot can identify crop rows and modify its orientation, direction, and path of travel.

5. CONCLUSION

Agriculture faces challenges in integrating Information Technology due to economic and environmental risks. Therefore, in the near future, agriculture will scarcely use effective instruments for plant pathology management or agricultural practices, assuming any exist at all or might be optimized. assuming they do, they will only be used on larger farms. Information technology may benefit from certain agricultural industry quirks, such as its use in "Food from Somewhere" programs. The outcome was what McMichael (2002) called the "Food from Nowhere" regime—a strong liberalization and commoditization of corporate supply networks, typified by standardizing manufacturing standards and working against regional identities to foods. But unlike the previous regimes, this one appears to have a persistent cultural frame (the cheap food era) as well as a developing, serious issue with cultural legitimacy.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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