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Research Article

Leveraging Mobile Phones in Crop Pests and Disease Surveillance - Perspectives of Farmers in Kenya

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Abstract

Agriculture plays a crucial role in ensuring food security and employment in Kenya. However, farmers in the country have been struggling with low crop yields due to pests and diseases. To address this issue, mobile-based digital surveillance technologies have been recommended as potential solution. However, these technologies have not been widely adopted by farmers, prompting this study to investigate the reasons behind this and propose strategies to improve their uptake. This paper reports on the farmers perspectives in Homa Bay County, Kenya on the adoption of mobile phone based digital tools in crop pest and disease surveillance. The study employed quantitative approach, involving surveys with 326 selected farmers. The study identified several factors contributing to the low adoption, including lack of training and capacity building, limited technical support to the farmers, limited access to necessary infrastructure, and neglect of co-creation of these solutions with the farmers. Given these findings, it follows that these solutions are intentionally designed to be farmer-centric, and handholding provided to the farmers on use of these technologies including providing farmer training and capacity building.

Introduction

The world's growing population, expected to reach 10 billion by 2050, is placing immense pressure on farmers to double their food production amidst worsening climate conditions and increasing crop pests and diseases [1,2]. Sub-Saharan Africa, including Kenya, faces concerns regarding food security and socio-economic development, as smallholder farmers, who are economically and technically disadvantaged, struggle to combat crop pests and diseases [3]. In Kenya, agriculture plays a vital role, employing 70% of the rural population, contributing approximately 27% to the Gross Domestic Product (GDP), and accounting for 65% of export earnings in 2020 [4]. However, despite its potential to improve food security and economic growth, crop production in Kenya is increasingly uncertain due to frequent pest attacks and a decline in agricultural knowledge delivery systems [5,6]. For instance, the spread of Fall Armyworm and Maize Lethal Necrosis Disease (MLND) caused significant losses for smallholder maize farmers in Western Kenya and North Rift, with up to a 50% crop loss in 2018 [7].

To address these challenges, digital surveillance methods have been recommended to enhance early detection, identification, and management of pests [8]. Although traditional surveillance methods involving extension officers have been employed, their effectiveness in Kenya is hindered by a shortage of officers relative to the vast geographic regions they are expected to cover [9,10]. As a result, agricultural technologies (Agri-tech) have emerged, aiming to digitize pest surveillance and control [11]. These Information and Communication Technologies (ICTs) have led to the development of mobile-based digital solutions for monitoring crop pests and diseases, offering farmers the ability to report threats and access advisory and technical support [12]. However, the slow adoption of these digital solutions by farmers in Kenya undermines the intended benefits of Agri-tech innovations aimed at improving agri-food systems in the region [13]. This study examines the key factors affecting the adoption of mobile-based pest surveillance solutions and proposes strategies to enhance their uptake among farmers in Kenya.

Problem Definition

Traditional surveillance methods are insufficient in meeting the evolving surveillance requirements for timely and accurate reporting of crop pests and diseases. While remote sensing technologies have proven successful in developed countries, their implementation in developing nations remains challenging due to high costs, technical requirements, and regulatory constraints. As an alternative, mobile-phone based surveillance solutions offer promise for addressing surveillance challenges in developing countries, including Kenya. However, despite the increasing mobile penetration, relatively low implementation costs, and improvements in cellular network infrastructure in Kenya, these solutions have not been widely adopted by farmers. This study aims to identify the key underlying factors contributing to the low adoption of mobile-based digital surveillance solutions among farmers in Kenya. By identifying and addressing these factors, the study seeks to enhance the adoption of mobile-based solutions, improve pest surveillance and control, and ultimately enhance crop productivity, food security, and economic growth in Kenya. The paper is structured as follow: Section 3 presents Related Work, Materials and Methods are presented in section 4 while Results and Discussion, and Conclusion, are presented in section 5 and 6 respectively.

Related Work

The research interest in automating crop pest and disease monitoring has led to significant attention in computer vision techniques, machine learning, and automated insect pest recognition [14]. Artificial Intelligence (AI) has enabled the simulation of human intelligence in ICT systems, empowering them to perform tasks such as visual perception on crops and decision-making [15]. To address pest management challenges in Kenya, various authors have recommended the adoption of digital technologies for improved access to modern agricultural support systems [16-19]. These technologies encompass a wide range, from simple offline farmer advisory digital videos to sophisticated systems like distributed ledger technologies for value chain traceability [20]. Additionally, Remote Sensing, Internet of Things (IoT), and Big Data Analytics (BDA) have gained endorsement for tracking, monitoring, automating, and analyzing agricultural operations [21,22]. The emerging monitoring technologies encompass various aspects, including mobile devices, in-field sensors, and remote sensing technologies [23]. As the digitization of crop protection progresses towards data-driven, farmer-centered, and knowledge-based decision-making, hybrid cloud environments offer a platform for integrating, aggregating, and interoperating customized digital solutions for farmers [24,25].

The potential benefits of technological advancements in pest monitoring, pest data management, incidence reporting, and information sharing have yet to be fully realized in Kenya. Currently, it is challenging to obtain real-time information on the prevalence of crop pests and diseases across the country due to fragmented and disconnected pest monitoring initiatives [26]. The coordination between first detectors and downstream responders remains inefficient and poorly coordinated [27]. Moreover, the collection and storage systems for pest data are inadequate, and there is a lack of established information sharing structures and communication protocols [28]. While National Plant Protection Organizations (NPPOs) and Regional Plant Protection Organizations (RPPOs) strive to monitor and contain pest and disease outbreaks, the sharing of outbreak information among low-income countries is often inefficient, resulting in delays in coordinating transnational efforts to control the spread and establishment of crop pests and diseases [29]. Individuals and organizations that collect valuable pest data through their own surveys often withhold it from other key stakeholders, contributing to a culture of data hoarding. Consequently, the existing crop pest data remains isolated in separate "silos," providing only fragmented insights into the national pest situation [30]. To improve national, regional, and global food systems, it is crucial to consolidate and centralize the vast amount of crop pest data and information currently held by various government and research institutions. This consolidation would facilitate data-driven pest interventions and enhance the decision-making process [16,25,31-33].

The utilization of Internet of Things (IoT) and Remote-Sensing (RS) technologies shows promise in the realm of pest and disease monitoring. These technologies enable real-time video monitoring of pests and diseases, as well as the development of early warning systems for predicting their occurrence [34,35]. However, in the field of RS, significant research challenges exist, particularly in the selection of sensor types and platforms, as well as the development of machine learning methods to analyze complex datasets for a deeper understanding of plant phenology [36]. Conversely, the evolution of mobile phones from basic voice and text communication devices to multifaceted platforms capable of capturing, processing, and transmitting various types of data has revolutionized the landscape of pest surveillance and control [37]. Advances in semiconductor technology have facilitated the integration of numerous physical sensors (such as positioning sensors, gyroscopes, motion sensors, accelerometers, and high-resolution cameras) into mobile phones [38,39]. The proliferation and diversity of these sensors, combined with the mobility of mobile phones, provide a unique opportunity for sensing diverse data with precise spatio-temporal coverage [40]. Furthermore, the enhanced processing power, increased memory, and expanded storage capacities of mobile phones have made it possible to run complex applications in various domains, including agricultural systems, health monitoring, environmental monitoring, and traffic monitoring [41]. Mobile phone applications based on artificial intelligence (AI) have the potential to offer farmers and extension agents an effective, low-cost, and user-friendly solution for pest and disease diagnostics [42,43].

The utilization of mobile-based pest management applications, referred to as "Agri-Apps," offers substantial assistance to farmers in pest identification, diagnosis, infestation reporting, and control solutions, thereby enhancing pest and disease surveillance in the region [44]. The adoption of these applications can be facilitated through a participatory approach, encouraging active engagement from farmers. Participatory sensing, also known as citizen science, is a social-technical paradigm in which mobile device users collect and share data about their environment using the Mobile Crowd Sensing (MCS) technique [45]. MCS, a term coined by Ganti et al. [46] involves multiple participants utilizing the sensors on their smart devices to contribute to large-scale and complex sensing tasks, harnessing the collective intelligence of the crowd [47]. The widespread availability of mobile phone devices and expanding network coverage presents an unprecedented opportunity for acquiring and transmitting spatially-oriented pest data [48]. Through embracing MCS, farmers as a collective crowd can provide real-time surveillance data throughout the year on the severity of crop diseases and pest incidences. While the potential for mobile-based surveillance applications to significantly mitigate pests and diseases in Kenya is evident, the prevailing reality reveals a low adoption rate among farmers [49-51]. Therefore, this study was purposed to investigate the underlying reasons for this low adoption rate and propose strategies to enhance the uptake of emerging mobile-based digital surveillance solutions.

Material and Methods

For this study, a quantitative approach was used to collect data from farmers. A survey questionnaire was given to 326 farmers purposively selected from the 4,389 farmers registered with the county's Directorate of Agriculture under various farm groups [52]. The study was conducted in Homa Bay County, Kenya, which has an area of 3,183.3 sq. km and a population of approximately 1.132 million people residing in 262,036 households [53]. The county's primary economic activity is agriculture, mainly carried out by 193,000 smallholder farmer households who frequently face crop pest and disease outbreaks [54]. To ensure the research instruments' reliability and validity, a pilot study was conducted in Kitutu Chache South Sub-County, Kisii County. The piloted questionnaire items were reviewed by experts and assessed for internal consistency using the Cronbach Alpha coefficient. The assessed constructs demonstrated alpha values higher than 0.7, indicating acceptable internal consistency [55,56]. Descriptive statistics were used to analyze the quantitative data collected through the survey. The Statistical Package for the Social Sciences (SPSS) version 25 was used for statistical analysis, and the results were presented through tables and charts for discussion. Findings were described using percentages, means, and standard deviations.

Results and Discussion

This section presents the findings and discussions pertaining to the factors that are expected to impact the adoption of mobile-based e-surveillance technologies. Additionally, it provides recommendations to address any obstacles that may impede the adoption of e-surveillance solutions among farmers in Kenya. The key factors investigated include digital infrastructure, socio-economic aspects, technical support, training and capacity building, digital literacy, and solution development methodology.

Digital infrastructure

According to the study by Smith and Thompson [57], the adoption of mobile-based surveillance technology heavily relies on critical infrastructure components, such as mobile phone devices, electricity, and cellular networks or Wi-Fi connectivity. Without these essential infrastructure elements, the adoption of mobile-based digital solutions in the surveillance domain remains unattainable.

Access to mobile phone devices

Mobile device accessibility plays a pivotal role in the development and adoption of mobile-based surveillance solutions, as it enables farmers to capture, analyze, and transmit pest-related data/information. According to Statista [58], the global ownership and usage of smartphones are rapidly growing, with an estimated 6.38 billion smartphone users worldwide currently, projected to reach 7.49 billion by 2025, indicating that approximately 80.63% of the world's population will own a smartphone. Recent research highlights a global improvement in mobile phone ownership over the past few years, with increased access to mobile devices among people residing in rural areas of developing countries [59]. This significant increase in mobile device penetration presents a favorable opportunity for adopting mobile-based e-surveillance solutions for pest and diseases. In Kenya, the Communications Authority (CA) reported in 2017 that the country had 40.0 million mobile subscriptions, with a penetration rate of 90.4% [60]. The CA's fourth-quarter sector statistics report of 2022 indicated a further rise in mobile subscriptions to 65.7 million, making Kenya the top African country in terms of mobile phone penetration [61]. This trend demonstrates a steady growth in the number of mobile phones and internet accessibility, with an average citizen often owning more than one phone. According to the study findings presented in Table 1, it was discovered that out of the 326 participating farmers, a significant majority of 315 farmers owned a mobile device, resulting in a high ownership rate of 96.6%. In addition, within the group of mobile phone owners, it was found that 35.6% (116 farmers) possessed basic feature phones, while 61% (199 farmers) had smartphones. Furthermore, the study revealed that out of the 39.0 (127 farmers) who did not own smartphones or any phones, a total of 14.1% (46 farmers) had access to smartphones belonging to other members within their households. As a result, 75.1% (245 farmers) have the opportunity to utilize the capabilities of smartphones for their surveillance initiatives. Regarding USSD-based surveillance services, which can be accessed even with basic feature phones, a significant majority of 98.16% (320 farmers) have the ability to participate.

Table 1: Access to smartphones among farmers.

			Without smartphone but can access within household	
		Total	No	Yes
Type of phone owned	None	11 (3.4%)	6	5
	Basic feature phone	116 (35.6%)	75	41
	Smartphone	199 (61%)		
Do not own smartphones		127 (39.0%)	81	46
Can access to smartphones*		245 (75.1%)		

*There are 199 farmers who own smartphones, while an additional 46 farmers do not own smartphones themselves but have access to smartphones within their households.

The extensive ownership of mobile phones among farmers in Kenya presents a promising opportunity for leveraging mobile-based technologies in agriculture, particularly for e-surveillance solutions. The widespread access to mobile phones implies that farmers have the necessary tools to engage with mobile applications and utilize them for e-surveillance purposes. This favorable landscape creates an enabling environment for the implementation and promotion of e-surveillance solutions in the country. Given the widespread use of mobile phones, it becomes more feasible to distribute e-surveillance technologies, provide real-time information, and involve farmers in effective monitoring of pests and diseases. Moreover, the existing familiarity with mobile phones among farmers simplifies the adoption of mobile-based e-surveillance technologies, making them more accessible and user-friendly.

Accessibility to electricity

Access to electricity is crucial for mobile device usage as it enables the recharging of device batteries. Most digital devices, including mobile phones, rely on a power source such as the national grid or rechargeable batteries. However, in rural areas where electricity supply is limited, the process of digitization among rural farmers becomes challenging. Recognizing the importance of infrastructure, the Government of Kenya has prioritized improving access to modern energy, particularly through rural electrification initiatives since 2008 [62]. These efforts have led to significant improvements in access to electricity, with approximately 62% of rural areas covered by rural electrification projects, allowing over 75% of the Kenyan population to have access to electricity [4]. Despite these achievements, many rural households still remain unconnected due to the high installation costs, which are often unaffordable for most farmers. While Kenya has higher rates of electricity access compared to other Sub-Saharan African countries [63], the issue of affordability continues to hinder connectivity for many rural farmers. The study revealed that 76% of the participating farmers had access to electricity, which is crucial for the adoption of digital surveillance in agriculture. This significant percentage of farmers with electricity access plays a vital role in ensuring smooth functioning of digital surveillance systems. It provides a reliable power supply for continuous operation of surveillance systems and enables farmers to keep their mobile devices charged, allowing them to actively engage in and benefit from digital surveillance solutions. However, the 24% of farmers without access to electricity still pose a significant challenge. These farmers may hesitate to use their phones for surveillance activities, such as taking pictures and recording videos of crops, due to concerns about draining their phone's battery.

Network connectivity

Internet connectivity is crucial for farmers as it enables real-time data transmission, remote monitoring and control, access to online resources, and collaboration. It allows farmers to share information, monitor crops, receive timely alerts, and make informed decisions. It also empowers farmers to access surveillance systems remotely and collaborate with experts and peers, driving the adoption and improvement of e-surveillance practices. Recent advancements in ICTs, such as high-speed and affordable broadband, big data, cloud computing, and mobile technologies, have created opportunities for technological innovations in agriculture [64]. The Kenyan government has demonstrated its commitment to the digital economy by establishing a supportive ICT infrastructure network and policy framework for agricultural transformation. As of 2017, 70 percent of rural Kenya was covered by 3G network services, and the adoption of mobile technology and internet has rapidly progressed, with 3G services reaching 95.8 percent of the population and 4G coverage at 64.3 percent [4,60]. Mobile technology and mobile Internet services have rapidly advanced, with 3G coverage reaching 95.8% of the population, 4G coverage reaching 64.3%, and the implementation of 5G underway [4]. By the end of 2019, there were 39.7 million active data subscriptions, with 22.1 million being broadband subscriptions [4]. The government has invested in broadband connectivity, deploying undersea fiber optic cables and extending the National Optic Fibre Broadband Infrastructure (NOFBI) network to all 47 counties [4]. Furthermore, statistics indicate a significant number of 3G and 4G broadband subscriptions, showcasing the availability of network infrastructure in Kenya [61] and Kenya's readiness to implement e-surveillance solutions. According to WorldBank [65], while mobile network coverage is generally considered adequate for farmers to access cellular networks in many African countries, the cost of internet access remains a significant barrier. Additionally, Table 2 shows that most farmers confirm that mobile network coverage is satisfactory (mean=4.2301, SD=0.65573), enabling them to access cellular networks without difficulty. However, most farmers perceive the cost of airtime and bundles as excessively high and recommend subsidies or compensation to cover the expenses associated with sensing (mean=4.5092, SD=0.5477).

Table 2: Access to Internet connectivity.

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic
The cost of airtime and bundles are too high need to be subsidised.	326	1	5	4.5092	0.5477
Network coverage in my area is adequate	326	1	5	4.2301	0.6557

(Likert Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree).

The findings on infrastructure indicate that farmers in Kenya have a significant opportunity to embrace mobile-based digital surveillance solutions for crop pests and diseases. They possess widespread ownership of mobile devices and have access to mobile networks and electricity. However, the cost of airtime and data bundles can hinder adoption, especially for online activities. To encourage adoption, providing incentives based on farmers' engagement can serve as a motivating factor, leading to improved crop management.

Access to technical support for farmers

Access to technical support services plays a crucial role in the successful adoption of agricultural technologies by farmers [66,67]. Developing countries have experienced challenges in the adoption of digital technologies due to weak support systems [68,69]. The limited availability of experts providing support to farmers in rural areas of Kenya has had a significant impact on farmer literacy and the adoption of digital technologies [70]. This lack of support has contributed to low levels of farmer literacy, making it challenging for farmers to effectively adopt and utilize digital technologies. The adoption of mobile or computer-based agricultural technologies faces challenges, especially among older adults who lack adequate support systems and may be technophobic [71]. In Kenya, farmers have traditionally relied on extension officers for support in adopting agricultural technologies [72]. However, the number of agricultural extension officers is decreasing, which poses a risk to the success of technology dissemination programs unless alternative support systems are implemented [73]. The role of extension officers as the main support system for farmers in introducing new agricultural technologies is important in Kenya. The findings in

Table 3 reveal challenges regarding the level of support provided by extension officers. Farmers generally feel that the current support and advice for controlling crop pests and diseases are insufficient (mean = 3.9877, SD = 0.7605). Additionally, farmers believe that access to agricultural experts for pest and disease management advice is not always guaranteed (mean = 4.2546, SD = 0.6560). Moreover, a significant number of farmers feel that the channels for seeking technical support are unclear (mean = 4.3006, SD = 0.6623). Overall, the average mean of 4.181 and a standard deviation of 0.6929 for the items related to the availability and adequacy of technical support indicate significant challenges in providing sufficient support to farmers.

Table 3: Descriptive Statistics on availability and adequacy of technical support.

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic
The current level of support and advice given to farmers in controlling crop pest and diseases is inadequate	326	1	5	3.9877	0.7605
Getting access to agricultural experts for advice on pest and disease management is not always guaranteed.	326	2	5	4.2546	0.6560
Channels for seeking technical support is not clear to many farmers.	326	2	5	4.3006	0.6623
Average Mean				4.181	0.6929

(Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree).

In addition to the challenges faced by farmers in accessing support services, the study found that 92% (23) of extension officers also expressed dissatisfaction with the inadequate technical support provided to both farmers and extension officers when digital solutions were introduced. Despite the introduction of digital applications to extension officers during their training as plant doctors by CABI, digital solution provider, it was found that 80% of the officers faced challenges in using these applications effectively. Although they were provided with tablets preinstalled with pest monitoring applications, they encountered difficulties because the tablets required updates. Unfortunately, the officers lacked the technical expertise to perform the updates themselves and did not receive adequate support to address this issue. As a result, the full potential of the applications could not be realized due to the inability to update the devices and receive necessary technical assistance.

In order to enhance the accessibility and reliability of support services, it is important to replace traditional support systems with automated solutions that can be accessed by farmers and extension officers at any time. By automating support services, the availability of high-quality and dependable support systems can be improved, while also strengthening the connection between farmers and support systems. This, in turn, will facilitate the adoption of emerging digital solutions in agricultural practices.

Training and capacity building

Insufficient training and a lack of capacity building have been identified by multiple authors [30,74-76] as significant factors contributing to the poor adoption of digital pest solutions among farmers in developing countries. In particular, Ochilo, et al. [27] emphasized the low adoption of pest management strategies in Kenya due to farmers' limited capacity to implement these solutions. The successful utilization of new agricultural technologies necessitates comprehensive training programs to equip farmers with the necessary skills [30]. Alongside training farmers and enhancing their technological skills, it is important to empower them with the ability to accurately interpret the solutions provided by technology, particularly in the areas of identification and diagnosis. This empowerment will enable farmers to effectively harness the benefits of technology adoption. In the conducted study, it was discovered that 59.2% of the participating farmers had received some form of training on scouting techniques and pest identification. However, the research findings, as depicted in figure 1, indicate a lack of knowledge among most farmers regarding pests and diseases commonly affecting their crops. While 38.96% of the farmers considered their knowledge of pests and diseases to be moderate, 53.99% indicated a low level of understanding in this area.

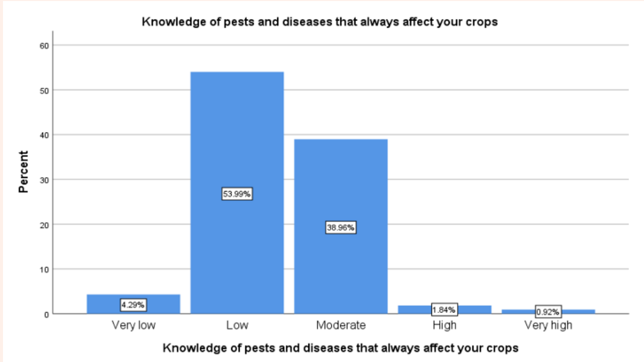

Figure 1: Level of farmers' knowledge in pest and disease

In addition to advocating for more training and capacity building, it is important to recognize that many rural farmers may have limited knowledge of entomology and crop science, as shown in the figure above. However, the emergence of Artificial Intelligence has brought forth new tools that can aid farmers in diagnosing, identifying, recording, describing, and reporting crop pests and diseases. Consequently, it is crucial to implement effective measures that focus on training farmers and strengthening their ability to adopt digital solutions for pest surveillance and control.

Digital solution formulation, development and implementation

As crop pests and diseases become a global concern, Agri-tech in Africa holds the promise of a better future as witnessed from the accelerated development of crop disease diagnostics and pest monitoring tools in the past decade [77]. Agri-tech solution providers including research institutes, universities and tech companies are continually coming up with agricultural decision tools to support farmers. The report by Africa's start-up portal, Disrupt Africa, shows that Kenya is a pioneer market for Agri-tech on the continent and accounts for 23.2 per cent of all African Agri-tech start-ups in Africa [78]. According to CGIAR [79], there are about 113 institutions offering digital solutions for Agriculture in Kenya from whom about 14 agribusiness apps were launched in Kenya during the East African Farmers Digital Conference in 2018. These Agri-tech startups which were meant to change the traditional ways of farming by blending it with technology are yet to have a major impact on the way information about pest and disease are gathered, stored and accessed [80,81].

Despite the existence of various digital pest management solutions some of which are freely available, the findings indicated that only 10.43% (34) of farmers were aware of the existence of Agri-tech solutions aimed at curbing crop pest and disease. The low uptake of most of the digital solutions could be attributed to lack of awareness of the existence of these solutions among farmers. From the interviews, 64% (16) of the extension officers considered lack of exposure and initial involvement of farmers in the solution formulation as a hinderance to the adoption of emerging agricultural digital surveillance technologies. The finding concurs with Akuku, et al. [82]'s assertion that most of the city-based solution developers are not privy to the specific needs of the farmers in the rural areas as they develop some of the solutions without clear understanding of the farmers operations in the rural areas, thereby resulting into a mismatch between developed solution and farmers' needs. Therefore, to enhance adoption of digital solutions by farmers in the rural settings, urban-centric initiatives seeking to solve agricultural problems should be guided by the needs and experience of the farmers. Unless farmers are in some way incorporated in the initial digital solution formulations and development, they will always be cynical about the promise of upcoming technologies and what the solutions can actually deliver.

Digital literacy and education

Digital literacy refers to the competency and proficiency in utilizing digital solutions [83]. It is noteworthy that many digital solutions aimed at farmers are primarily accessible in English or, to a lesser extent, Kiswahili, requiring a basic level of education [4]. However, this study reveals that approximately 75% of farmers have achieved at least a secondary level of education, enabling them to engage with digital content and solutions in English. In the context of e-surveillance, which involves the utilization of technologies like the internet and mobile devices, farmers must possess the necessary skills to effectively operate these tools.

To assess farmers' proficiency in phone usage, the findings in Table 4 revealed that the majority of farmers were able to utilize basic functions such as short text messaging service (Mean=3.6718, SD=1.4010), which is a requirement for USSD services. Similarly, most farmers reported their ability to use money transfer services (Mean=4.0276, SD=1.0149) and make phone calls (Mean=4.3773, SD=1.0116). However, most farmers need to enhance their skills in capturing and sharing pictures and videos, as they demonstrated a neutral stance on their ability to do so (Mean=3.3957, SD=1.1421). Likewise, farmers expressed uncertainty regarding their capability to install and configure mobile apps (Mean=3.0460, SD=1.33164). Accessing the internet and using social media platforms were identified as challenges for most farmers, as they struggled to browse the internet (Mean=2.6626, SD=1.1621). Moreover, social media platforms, particularly WhatsApp, have not gained widespread popularity among farmers for sharing and discussing information (Mean=2.2822, SD=1.0168).

Table 4: Descriptive Statistics of digital literacy.

	N Statistic	Minimum Statistic	Maximum Statistic	Mean Statistic	Std. Deviation Statistic
DL1. Comfortably write, read and send text messages with my phone.	326	1	5	3.6718	1.4010
DL2.Take pictures/ video with a smartphone and share with others	326	1	5	3.3957	1.1421
DL3. Download, install and operate an application on a phone	326	1	5	3.0460	1.3316
DL4. Carry out mobile Money transfer Services (M-Pesa Services)	326	1	5	4.0276	1.0149
DL5. Making and receiving of calls	326	1	5	4.3773	1.0116
DL6. Access and browse the internet	326	1	5	2.6626	1.1621
DL7. Accessing social media (WhatsApp, Facebook, Twitter)	326	1	5	2.2822	1.0168
DL8.I may need the digital content availed in my language.	326	1	5	2.5429	1.045
DL9. The digital technologies are reliable and trusted	326	1	5	3.911	0.9388
DL10. There is need to acquire the required technical skills/knowledge	326	1	5	3.3221	1.0887
Average Mean				3.3239	1.1153

According to the surveyed extension officers, low digital literacy is identified as a significant challenge in the adoption of digital surveillance solutions by farmers, with 80% of officers acknowledging this issue. The study findings (Table 4) indicate that most farmers (Mean = 2.543, SD = 1.045) do not require digital content to be translated into their local language, as it may result in a loss of meaning. Additionally, the majority of farmers (Mean = 3.911, SD = 0.939) expressed trust and reliability in digital technologies, perceiving them as useful tools for their needs. On average, farmers recognized the importance of acquiring technical skills and knowledge to effectively use information and communication technology (ICT) for pest and disease surveillance. However, the overall digital literacy level of farmers indicated a neutral position, suggesting room for improvement through training and awareness initiatives. To enhance digital literacy among farmers, targeted efforts should focus on providing training and support to improve their proficiency in using mobile devices, capturing media, installing apps, accessing the internet, and utilizing social media platforms. By improving their digital literacy, farmers can effectively utilize e-surveillance tools for better pest management and information exchange.

Influence of demographic factors in E-Surveillance adoption

Demographic characteristics, such as gender, age, and education, have been identified by researchers as significant factors that can influence the adoption of agricultural technologies [76,84,85]. Gender disparities can pose challenges to technology adoption, particularly for women farmers, who may encounter barriers to access and face cultural restrictions. In Kenya, cultural norms frequently favor men, granting them greater rights over agricultural land and decision-making authority regarding land usage [84]. Women face social oppression and economic inequality, which can limit their access to resources, including ICT equipment. This gender disparity, along with gender norms and perceptions of technology, can hinder women farmers from adopting agricultural technologies [86]. The demanding nature of women's household chores and family responsibilities may also restrict their availability to attend the trainings necessary for implementing new agricultural technologies [87]. Traditionally, agriculture in many rural areas of Africa has been predominantly associated with women [88]. Based on the research findings in table 5, there is a relatively equal distribution of female and male farmers within Homabay County, with a ratio of approximately 1:1. This balanced gender distribution helps minimize the potential bias in technology adoption based on gender. The findings in table 6 below demonstrate that ownership of mobile phones is evenly distributed between men and women, as indicated by a normal distribution.

Table 5: Gender Disparities in Phone Ownership.

Count					
		Type of phone owned			Total
		None	Basic phone	smartphone	
Gender	Male	7	56	98	161
	Female	4	60	101	165
Total		11	116	199	326

Gender * type of phone owned Crosstabulation.

Different age groups have varying levels of interaction and understanding when it comes to digital technology [89]. While the aged are often more technophobic compared to young people [90], it is a misconception to assume that all elderly farmers are resistant to adopting new technologies. In the past, agriculture has been perceived as an occupation for older rural individuals, but with the increasing problem of youth unemployment, more young people are considering agriculture as a viable option [86,90,91]. The findings presented in Table 6 illustrate a shift in the demographics of farmers involved in crop farming. While the younger generation may be more adept at embracing emerging agricultural technologies, older farmers may require more time to familiarize themselves with these advancements. The findings presented in Table 6 indicate that phone ownership among farmers is distributed normally across different age groups. Studies have shown that many young people in Kenya are willing to embrace ICT applications in agriculture, especially through the use of smartphones and social media platforms [85,91]. While older farmers may exhibit some hesitation in adopting new technologies and may require additional time to become familiar with ICT operations, younger farmers who are actively engaged in agriculture can provide support and guidance to assist them in catching up with technology advancements.

Table 6: Age Disparities in Phone Ownership.

Count					
		Type of Phone Owned			Total
		None	Basic phone	smartphone	
Age	18-30 Years	5	17	22	44
	31-40 Years	0	33	74	107
	41-50 Years	4	30	61	95
	51-60 Years	1	15	28	44
	Over 60 Years	1	21	14	36
Total		11	116	199	326

Age * type of phone owned Cross-tabulation.

In order to promote the adoption of mobile-based surveillance in agriculture, it is important to address barriers based on demographics. This includes providing training programs, improving digital literacy, bridging infrastructure gaps, ensuring affordability, and promoting gender equality. By taking these steps, farmers from diverse backgrounds can benefit from mobile-based e-surveillance. To effectively automate crop pest and disease surveillance, it is crucial to strengthen the capacity of all farmers as key partners in the implementation process, regardless of their gender. Addressing gender-based barriers, incorporating gender sensitivity in technology adoption, and creating an enabling environment for women's participation are vital for fostering technology adoption among women farmers [88,92].

Though the current phone penetration, cellular network coverage and electricity coverage present an opportunity for adoption of mobile-based surveillance solutions by farmers, the cost of connectivity remains a significant barrier. Insufficient technical support presents a challenge to the adoption and effective use of mobile-based surveillance solutions. Similarly, the study identified lack of training and capacity building as barriers to the adoption of mobile-based solutions. The low adoption of mobile-based digital solutions among farmers is also attributed to lack of farmer involvement in the development process resulting in to developer centric solutions as opposed to farmer centric solutions which minimized mismatch between the needs of the farmers and the solutions. Despite the adoption challenges identified by the study, the participation of both men and women in farming can accelerate the adoption of mobile-based surveillance solutions by fostering diversity, collaboration, and support. Similarly, having farmers of different ages brings technological diversity and inter-generational learning. By leveraging the strengths and knowledge of older and younger farmers, a supportive environment for embracing new technologies is created while preserving traditional farming wisdom. Though most farmers are able to use their phones in carrying out mobile basic operation such as making calls, mobile money transactions, and short text messaging, operations such as accessing the internet, downloading of applications and manipulation of multimedia content remain a challenge to most framers. Improving farmers' access to infrastructure, technical support, training, and capacity building is expected to enhance the adoption of mobile-based surveillance solutions.

To improve the adoption of mobile-based digital surveillance in crop pest management and harness the potential of mobile phones in this context, an adoption framework (Figure 2) is proposed. This framework emphasizes the critical components necessary for accelerating the adoption of mobile-based surveillance solutions by farmers. The Framework consists of training and capacity building, technical support, digital infrastructure, farmer-centric solutions, and gender inclusivity.

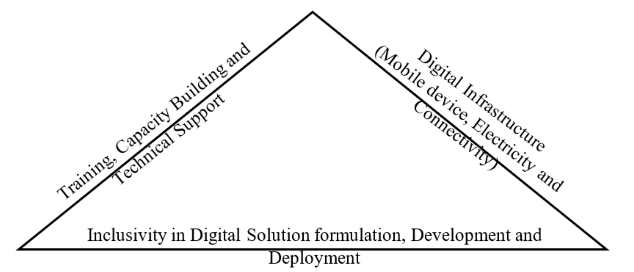

Figure 2: Digital Surveillance Adoption Framework.

Training and capacity building aim to equip farmers with the necessary knowledge and skills, while technical support provides assistance with troubleshooting and maintenance. Digital infrastructure ensures farmers have access to necessary resources, and farmer-centric solutions involve farmers in the development process. Gender inclusivity promotes equal participation of both men and women. Together, these components form a comprehensive framework to facilitate the adoption of mobile-based surveillance solutions in agriculture.

Conclusion

Agriculture is vital for food security and employment in Kenya, with a positive shift in farming trends towards more young people and diverse genders embracing agriculture. However, crop pests and diseases continue to pose significant challenges, impacting agricultural productivity. Mobile-based solutions have been proposed for adoption by farmers to assist in the surveillance and control of crop pests and diseases. While there are opportunities to leverage these solutions in pest surveillance and control, inadequate training and capacity building, weak support systems, limited access to necessary infrastructure, and lack of inclusivity in development of these solutions, were identified as factors contributing to the low adoption of mobile-based solutions. Given the findings above, there is need to subsidize costs of connectivity, improve access to infrastructure, and strengthen links between farmers and support systems. The solutions should be intentionally designed to be farmer-centric while proving handholding to the farmers on use of these technologies including providing farmer training and capacity building. In addition, effort should be made to ensure equal access to required resources irrespective of demographic factors such as age, gender or education. As efforts are made to improve the adoption of mobile-based digital surveillance solutions, it is also important to consider incentivization for farmers participation in the surveillance since farmers are like to incur costs related to time, effort and phone resources. Future research is necessary to establish how subsidies, enhance training, technical support and accessibility to infrastructure could be used as incentives to ensure sustainability and scalability of mobile-based surveillance solutions.

References

1. Guru PPG, Adak T, Gowda B, Patil N, Annamalai M, et al. (2018) Toxicological effect of underutilized plant. Cleistanthus collinus leaf extracts against two major stored grain pests, the rice weevil, Sitophilus oryzae and red flour beetle, Tribolium castaneum. Ecotoxicology and environmental safety 154: 92-99.
2. FAO (2017) The Future of Food and Agriculture: Trends and Challenges.
3. Pratt CF, Constantine KL, Murphy ST (2017) Economic impacts of invasive alien species on African smallholder livelihoods. Global Food Security 14: 31-37.
4. FAO and ITU (2022) Status of digital Agriculture in 47 Sub-Saharan African countries. FAO and ITU, Rome.

5. World Bank (2019) Kenya Economic Update: Transforming Agricultural Productivity to Achieve Food Security for All.
6. Zahran Y, Kassem HS, Naba SM, Alotaibi BA (2020) Shifting from Fragmentation to Integration: A Proposed Framework for Strengthening Agricultural Knowledge and Innovation System in Egypt. Sustainability 12(12): 5131.
7. FAO (2019) Pest Control on the Go: A Mobile App for Monitoring and Early Detection of fall Armyworm.
8. Sappington TW, Hesler LS, Allen KC, Luttrell RG, Papiernik SK (2018) Prevalence of Sporadic Insect Pests of Seedling Corn and Factors Affecting Risk of Infestation. Journal of Integrated Pest Management 9.
9. UN (2020) East Africa locusts threaten food security across subregion, alerts UN agriculture agency.
10. MoALF (2016) Climate Risk Profile for Homa Bay County. Kenya County Climate Risk Profile Series. The Ministry of Agriculture, Livestock and Fisheries (MoALF), Nairobi, Kenya.
11. Reddy PP (2018) Crop Protection Strategies: Under Climate Change Scenarios. Scientific Publishers, Delhi, India.
12. Singh N, Gupta N (2016) ICT based decision support systems for Integrated Pest Management (IPM) in India: A review. Agricultural Reviews 37: 309-316.
13. Kabbiri R, Dora M, Kumar V, Elepu G, Gellynck X (2018) Mobile phone adoption in agri-food sector: Are farmers in Sub-Saharan Africa connected? Technological Forecasting and Social Change 131: 253-261.
14. Wu X, Zhan C, Lai YK, Cheng MM, Yang J (2019) IP102: A Large-Scale Benchmark Dataset for Insect Pest Recognition. Presented at the Conference on Computer Vision and Pattern Recognition (CVPR), Long Beach, CA, USA.
15. Selvaraj MG, Vergara A, Ruiz H, Safari N, Elayabalan S, et al. (2019) AI-powered banana diseases and pest detection. Plant methods 15.
16. Anthony K (2017) Technology: The future of agriculture. Nature 544: S21-S23.
17. KARI (2019) The Major Challenges of The Agricultural Sector in Kenya.
18. Okonya JS, Ocimati W, Nduwayezu A, Kantungeko D, Niko N, et al. (2019) Farmer Reported Pest and Disease Impacts on Root, Tuber, and Banana Crops and Livelihoods in Rwanda and Burundi. Sustainability 11: 1592.
19. Zhai Z, Martínez JF, Beltran V, Martínez NL (2020) Decision support systems for agriculture 4.0: Survey and challenges. Computers and Electronics in Agriculture 170: 105256.
20. Rose DC, Chilvers J (2018) Agriculture 4.0: Broadening responsible innovation in an era of smart farming. Frontiers in Sustainable Food Systems 2: 87.
21. Wolfert S, Ge L, Verdouw C, Bogaardt MJ (2017) Big data in smart farming - a review. Agricultural systems 153: 69-80.
22. Walter A, Finger R, Huber R, Buchmann N (2017) Opinion: Smart farming is key to developing sustainable agriculture. Proceedings of the National Academy of Sciences 114(24): 6148-6150.
23. Caffaro F, Cavallo E (2019) The Effects of Individual Variables, Farming System Characteristics and Perceived Barriers on Actual Use of Smart Farming Technologies: Evidence from the Piedmont Region, Northwestern Italy. Agriculture 9: 111.
24. Xin J, Zazueta F (2016) Technology Trends in ICT - Towards Data-Driven, Farmer-Centered and Knowledge-Based Hybrid Cloud Architectures for Smart Farming. CIGR Journal 18(4).
25. Microsoft (2021) Research highlights opportunities for digitizing agriculture in Kenya.
26. CABI (2018) Addressing scale insect threats in Kenya.
27. Ochilo WN, Otipa M, Oronje M, Chege F, Lingeera EK, et al. (2018) Pest Management Practices Prescribed by Frontline Extension Workers in the Smallholder Agricultural Subsector of Kenya. Journal of Integrated Pest Management 9: 15.
28. Carvajal YM, Cardwell K, Nelson A, Garrett KA, Giovani B, et al. (2019) A global surveillance system for crop diseases: Global preparedness minimizes the risk to food supplies. Science 364(6447): 1237-1239.
29. UN (2019) Global Sustainable Development Report.
30. Eitzinger A, Cock J, Atzmanstorfer K, Binder CR, Läderach P, et al. (2019) GeoFarmer: A monitoring and feedback system for agricultural development projects. Computers and Electronics in Agriculture 158: 109-121.
31. Tricarico D, Darabian N (2016) mAgri- Weather forecasting and monitoring: Mobile solutions for climate resilience. GSMA.
32. FAO (2017) Information and Communication Technology (ICT) in Agriculture: a Report to the G20 Agricultural Deputies.
33. Kaka N, Madgavkar A, Kshirsagar A, Gupta R, Manyika J, et al. (2019) Digital India: Technology to Transform a Connected Nation. McKinsey Global Institute.
34. Yan X, Sun L, Zhou J, Song A (2018) DV-hop localisation algorithm based on optimal weighted least square in irregular areas. Electronics Letters 54(21): 1243-1245.
35. Wang S, Kim SM, Kong L, He T (2018) Concurrent transmission aware routing in wireless networks. IEEE Transactions on Communications 66(12): 6275-6286.
36. Kuska MT, Heim RHJ, Geedicke I, Gold KM, Brugger A, et al. (2022) Digital plant pathology: a foundation and guide to modern agriculture. Journal of Plant Diseases and Protection 29(3): 457-468.
37. Mutembesa D, Omongo C, Mwebaze E (2018) Crowdsourcing real-time viral disease and pest information: A case of nation-wide cassava disease surveillance in a developing country. In: Sixth AAAI Conference on Human Computation and Crowdsourcing.
38. Chessa S, Corradi A, Foschini L, Girolami M (2016) Empowering mobile crowdsensing through social and ad hoc networking. IEEE Communications Magazine 54: 108-114.
39. Huang KL, Kanhere SS, Hu W (2014) On the need for a reputation system in mobile phone based sensing. Ad Hoc Networks 12: 130-149.
40. Guo B, Wang Z, Yu Z, Wang Y, Yen NY, et al. (2015) Mobile Crowd Sensing and Computing: The Review of an Emerging Human-Powered Sensing Paradigm. ACM Computing Surveys 48: 1-33.
41. Mafrur R, Nugraha IGD, Choi D (2015) Modeling and discovering human behavior from smartphone sensing life-log data for identification purpose. Human-Centric Computing and Information Sciences 5: 1-18.
42. Chepkwony R, Bommel SV, Langevelde FV (2020) Citizen science for development: Potential role of mobile phones in information sharing on ticks and tick-borne diseases in Laikipia, Kenya. NJAS - Wageningen Journal of Life Sciences 86-87: 123-135.
43. CIP (2020) Smartphone-based diagnosis of crop diseases.
44. Panda CK (2018) Mobile Phone Usage in Agricultural Extension in India: The Current and Future Perspective. In: Mobile Technologies and Socio-Economic Development in Emerging Nations. In: Mtenzi FJ, Oreku GS, Lupiana DM, Yonazi JJ, (eds.), IGI Global, Hershey PA, USA: IGI Global, pp. 1-21.
45. Coulson S, Woods M, Scott M, Hemment D (2018) Making Sense: Empowering participatory sensing with transformation design. The Design Journal 21: 813-833.
46. Ganti RK, Ye F, Lei H (2011) Mobile crowdsensing: current state and future challenges. IEEE communications Magazine 49(11): 32-39.
47. Shu L, Chen Y, Huo Z, Bergmann N, Wang L (2017) When mobile crowd sensing meets traditional industry. Ieee Access 5: 15300-15307.
48. Ratliff LJ, Dong R, Sekar S, Fiez T (2019) A perspective on incentive design: Challenges and opportunities. Annual Review of Control, Robotics, and Autonomous Systems 2: 305-338.
49. Awuor FM, Otanga SA (2019) Farmer centered large scale e-surveillance and control of crop pests in Kenya. Journal of Agricultural Informatics 10: 33-44.
50. ICRISAT (2017) Mobile App for Pest and Disease Management of Crops.
51. FAO (2018) Nuru becomes African farmers' newest ally against Fall Armyworm.
52. HBC, "Title," unpublished.
53. KNBS (2019) 2019 Kenya Population and Housing Census: Volume IV.
54. HBC (2018) Homa Bay County Annual Development Plan 2018/2019. E. P. A. S. D. Department of Finance, ed: Homa Bay County.
55. Hayes F, Coutts JJ (2020) Use omega rather than Cronbach's alpha for estimating reliability. But…. Communication Methods and Measures 14: 1-24.

56. Madan R, Kensinger EA (2017) Test - retest reliability of brain morphology estimates. Brain informatics 4: 107-121.

57. Smith J, Thompson R (2022) Infrastructure Requirements for the Adoption of Mobile-Based Surveillance Technology. Journal of Surveillance Technology 45: 78-92.

58. Statista (2021) Forecast number of mobile users worldwide from 2020 to 2025.

59. Smith J, Johnson A, Williams R (2022) Accessibility to mobile devices as a catalyst for the development and adoption of mobile-based surveillance solutions among farmers. Journal of Agricultural Technology 26: 45-60.

60. CA (2017) First Quarter Sector Statistics Report for the Financial Year 2017/2018. In: CA Kenya, ed: Communications Authority of Kenya.

61. CA (2022) Fourth quarter sector statistics report for the financial year 2021/2022. Communication Authority of Kenya, Nairobi, Kenya.

62. Moner GM, Bódis K, Morrissey J, Kougias I, Hankins M, et al. (2019) Decentralized rural electrification in Kenya: Speeding up universal energy access. Energy for Sustainable Development 52: 128-146.

63. Lee K, Miguel E, Wolfram C (2018) The social and economic impacts of electrification: Evidence from Kenya.

64. OECD (2012) ICT infrastructures and ICT policies for innovation. Science, Technology and Industry Outlook 2012.

65. World Bank (2019) Future of Food: Harnessing Digital Technologies to Improve Food System Outcomes. World Bank Group.

66. Barnes AP, Soto I, Eory V, Beck B, Balafoutis A, et al. (2019) Influencing factors and incentives on the intention to adopt precision agricultural technologies within arable farming systems. Environmental science & policy 93: 66-74.

67. Soto D, Barnes A, Eory V, Beck B, Balafoutis A, et al. (2018) Which factors and incentives influence the intention to adopt precision agricultural technologies? Presented at the 30th International Conference of Agricultural Economists, Vancouver.

68. Nakasone E, Maximo T (2016) A Text Message Away: ICTs as a Tool to Improve Food Security. Agricultural Economics 47(1): 49-59.

69. Annosi MC, Brunetta F, Monti A, Nati F (2019) Is the trend your friend? An analysis of technology 4.0 investment decisions in agricultural SMEs. Computers in Industry 109: 59-71.

70. Mugendi J (2020) Challenges in Implementing Digital Technologies in Rural Kenya.

71. Marescotti ME, Demartini E, Filippini R, Gaviglio A (2021) Smart farming in mountain areas: Investigating livestock farmers' technophobia and technophilia and their perception of innovation. Journal of Rural Studies 86: 463-472.

72. Nzengu M (2021) Counties mustn't phase out extension officers. In Star, ed.

73. Nyarko DA, Kozári J (2021) Information and communication technologies (ICTs) usage among agricultural extension officers and its impact on extension delivery in Ghana. Journal of the Saudi Society of Agricultural Sciences 20(3): 164-172.

74. Baumüller H (2017) The Little We Know: An Exploratory Literature Review on the Utility of Mobile Phone Enabled Services for Smallholder Farmers. Journal of International Development 30(1): 134-154.

75. Shirur M, Shivalingegowda N, Chandregowda M, Rana RK (2016) Technological adoption and constraint analysis of mushroom entrepreneurship in Karnataka. Economic Affairs 61(3): 427.

76. Tata S, McNamara PE (2017) Impact of ICT on agricultural extension services delivery: evidence from the Catholic Relief Services SMART skills and Farmbook project in Kenya. The Journal of Agricultural Education and Extension 24: 89-110.

77. Ngunjiri (2018) Kenya top in Africa on agriculture tech startups. In: Business Daily, (ed.), Nairobi: Nation Media Group.

78. Jackson T (2019) African Tech Startups Funding Report 2019.

79. CGIAR (2020) Inspire Challenge: Monitoring Pests & Diseases.

80. Allen E (2019) Precision pest control: Smartphone app is the farmer's newest weapon in crop protection.

81. Ibrišević (2020) Agritech in Africa: Paving The Way For a New Era in Farming.

82. Akuku B, Haaksma G, Derksen H (2019) Digital Farming in Kenya, Embassy of the Kingdom of the Netherlands Nairobi, Kenya.

83. Pivoto D, Barham B, Waquil PD, Foguesatto CR, Corte VFD, et al. (2019) Factors influencing the adoption of smart farming by Brazilian grain farmers. International Food and Agribusiness Management Review 22: 571-588.

84. Gebre GG, Isoda H, Rahut DB, Amekawa Y, Nomura H (2019) Gender differences in the adoption of agricultural technology: The case of improved maize varieties in southern Ethiopia. Women's Studies International Forum 76.

85. Irungua RG, Mbuguaa D, Muia J (2015) Information and Communication Technologies (ICTs) Attract Youth into Profitable Agriculture in Kenya. East African Agricultural and Forestry Journal 81: 24-33.

86. Ndirangu W (2021) Agriculture Sector Set for Digital Transformation.

87. Nelson (2014) Pest Management Plan, A. I. a. F. A. C. D. P. Ministry of Agriculture, ed. Uganda: Republic of Uganda.

88. Achandi EL, Mujawamariya G, Agboh NAR, Gebremariam S, Rahalivavololona N, et al. (2018) Women's access to agricultural technologies in rice production and processing hubs: A comparative analysis of Ethiopia, Madagascar and Tanzania. Journal of Rural Studies 60: 188-198.

89. Dhraief Z, Bedhiaf RS, Dhehibi B, Oueslati ZM, Jebali O, et al. (2018) Factors Affecting the Adoption of Innovative Technologies by Livestock Farmers in Arid Area of Tunisia. Forum for Agricultural Research in Africa (FARA).

90. White B (2012) Agriculture and the Generation Problem: Rural Youth, Employment and the Future of Farming. IDS Bulletin 43: 9-19.

91. Khalid B, Al-Badri, Dhehibi B (2017) Economic Analysis of the Factors Affecting the Adoption of Sub Surface Irrigation Technology in Iraq. International Journal of Science and Research (IJSR) 6: 1777- 1783.

92. Adekemi (2014) Gender Differences in Technology Adoption and Welfare Impact among Nigerian Farming Households. MPRA Paper No. 58920.