Assessing Preparedness for Smart Farming and Technology Adoption among Kenyan Farmers

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ABSTRACT

Agriculture is crucial in reducing poverty, promoting economic prosperity, and ensuring food security for the world's growing population, which is expected to reach 9.7 billion by 2050. This sector is vital to the global economy, contributing significantly to GDP and providing jobs for a large workforce. Precision agriculture and e-commerce advances have proven beneficial, boosting crop yields and rural incomes. Sub-Saharan Africa faces similar agricultural challenges as it anticipates a population of 2.1 billion by 2050. Although the region has made strides in expanding farmland and labour, improvements in crop yields have been limited. The digital revolution offers new opportunities to tackle issues such as undernutrition by improving access to information and technology. In Kenya, with a population projected to reach 95 million by 2050, expanding food production is a pressing challenge. Significant hurdles include declining soil fertility, inadequate water management, and a lack of technical support. While technologies like Wireless Sensor Networks (WSNs) and Machine Learning (ML) have the potential to enhance agricultural productivity, their adoption is constrained by infrastructure issues, high costs, and a shortage of technical expertise. Addressing these barriers and improving farmer education is essential to fully realising these technologies' benefits.

Keywords: Smart Farming, Machine Learning, WSN, agricultural productivity

INTRODUCTION

The development of agriculture is crucial for eradicating poverty, fostering shared prosperity, and ensuring food security for the world's growing population, which is projected to reach 9.7 billion by 2050 [1]. Agriculture contributes one-third of the global GDP, and 28% of the global workforce is employed in agriculture and food production [2]. Precision agricultural technologies have increased yields by 10-15%, and e-commerce platforms have increased rural incomes by 20% on average [1].

Sub-Saharan Africa (SSA) shares challenges and opportunities in agriculture with the rest of the world. The region's population, currently 13% of the global population, is expected to reach 2.1 billion by 2050 [3]. Agricultural growth in SSA has been driven by increased acreage and a large labour population, but yield improvements have been modest [4]. The digital era offers technological alternatives to enhance agricultural productivity, addressing undernutrition, which stands at 23% in SSA, the highest among emerging regions [5]. Improved access to information, markets, inputs, training, and financing promised by Fourth Industrial Revolution (FIR) technologies is expected to enhance farmers' prospects significantly [6].

Kenya faces significant challenges in expanding food production to meet the needs of its growing population, which is expected to nearly double to 95 million by 2050 from 47.5 million in 2019 [7]. About 57.03% of Kenya's labour force comprises farmers, and the country's agricultural industry is dominated by small-scale farmers who have inadequate access to extension services compared to large-scale farmers. Kenya's agricultural productivity is hindered by declining soil fertility, inadequate water management, pest and disease outbreaks, and limited access to advisory services [8]. Advances in Information Technology (IT) are empowering Kenyan farmers with timely agricultural information, though the adoption of smart farming practices remains low. Access to smart farming systems significantly influences farmers' decision-making [9]. The role of ICT in agricultural advisory services is crucial, enabling farmers to make informed and timely decisions, thereby improving agricultural productivity [9].

Statement of the Problem

As global population growth intensifies, the demands on agricultural production are reaching unprecedented levels. With projections estimating a global population of 9 billion by 2050, there is an urgent need to increase agricultural output, reduce production costs, and conserve natural resources [10]. Concurrently, challenges such as climate change, urbanization, and overexploitation of agricultural lands contribute to a significant reduction in arable land, exacerbating the imbalance between production and consumption [11]. In Kenya, while Wireless Sensor Networks (WSNs) and Machine Learning (ML) hold substantial promise for enhancing agricultural productivity, their widespread adoption faces considerable hurdles. Infrastructure limitations, including unreliable electricity and inconsistent internet connectivity, impede the effective deployment of these technologies [12]. Additionally, the high costs associated with implementing WSNs and ML systems and data quality and availability issues further complicate their adoption [13]. A critical shortage of technical expertise for implementing and managing these advanced systems exacerbates these challenges (Gichuki, Mbuguah, & Mwangi, 2022). Furthermore, resistance from farmers—stemming from a lack of training and understanding of these technologies—hinders the integration of WSNs and ML with traditional agricultural practices [14].

LITERATURE REVIEW

As the global population approaches 9 billion by 2050, the demand for agricultural production is escalating. Their study [10] discusses the challenges and potential of implementing Agricultural 4.0 technologies. They emphasize that integrating advanced technologies like IoT, AI, and big data analytics in agriculture can significantly enhance productivity, sustainability, and resource management. However, they highlight several socio-economic barriers that could hinder these innovations' rapid scaling and effective implementation. These barriers include data security, privacy concerns, infrastructure limitations, and the digital divide. The study stresses the importance of addressing these challenges to ensure fair and responsible deployment of smart farming technologies.

[10] discuss the imperative to boost agricultural output while managing production costs and conserving natural resources. The study emphasizes that meeting these demands will require innovative approaches to enhance productivity and efficiency in agriculture. This growth underscores the necessity for adopting advanced technologies to ensure food security and sustainability. However, given the various socio-economic barriers, the study may overestimate the speed at which technological innovations can be scaled up and implemented effectively.

Climate change, urbanization, and overexploitation are significantly affecting the availability of arable land, exacerbating the imbalance between agricultural production and consumption. [11] explore how these factors lead to substantial losses in arable land, presenting serious challenges for maintaining the production-consumption balance. Reducing available land heightens the need for technologies to optimize agricultural practices and enhance productivity. The study provides valuable insights but may lack a detailed analysis of specific regional impacts, which is crucial for understanding localized challenges and solutions.

Infrastructure limitations, including unreliable electricity and inconsistent internet connectivity, hinder the adoption of Wireless Sensor Networks (WSNs) in agriculture. [12] investigate how these infrastructural barriers impede the effective deployment of WSNs in developing regions, such as Kenya. The study highlights the critical role of reliable infrastructure in facilitating the successful implementation of smart technologies in agriculture. However, the research could benefit from a more detailed exploration of potential solutions or innovations to address these infrastructure issues rather than just identifying the barriers.

High costs associated with setting up WSNs and Machine Learning (ML) systems pose significant barriers to their adoption. [13] examine the financial challenges and data quality issues that complicate the implementation of these technologies. Their research underscores the need for cost-effective solutions and improvements in data management to support the widespread adoption of smart farming technologies. A critical aspect missing from the study is an exploration of the cost-benefit analysis of these technologies, which could provide a more comprehensive understanding of their economic feasibility.

A shortage of technical expertise is a major obstacle to successfully implementing and managing WSNs and ML systems in agriculture. Aslam, Ahmad, and Hussain (2022) highlight the critical need for capacity building and training to address this gap. Their study emphasizes that developing the necessary skills and knowledge among stakeholders is essential for overcoming barriers to technology adoption. However, the study might benefit from a more nuanced discussion on how different training programs can be tailored to various levels of technical expertise and regional contexts.

Due to a lack of understanding and training, resistance from farmers hinders the integration of WSNs and ML with traditional agricultural practices. [14] address the role of training and education in overcoming this resistance. Their research suggests that targeted educational initiatives are crucial for bridging knowledge gaps and facilitating the adoption of advanced agricultural technologies. While the study provides a good overview of training needs, it may not fully address the socio-cultural factors influencing farmers' attitudes towards new technologies, which are critical for designing effective educational interventions.

This literature underscores the multifaceted challenges faced by Kenyans in adopting smart farming technologies. Addressing these challenges—ranging from infrastructure and cost issues to technical expertise and farmer resistance—is essential for leveraging the potential of WSNs and ML to enhance agricultural productivity and sustainability.

METHODOLOGY

A structured survey methodology was employed to assess the level of smart farming preparedness among Kenyan farmers. The survey was designed to capture data on technology usage, familiarity with smart farming concepts, and readiness to adopt new technologies.

The survey focused on several key areas, including device ownership, such as smartphones and laptops, and their frequency of use and comfort levels with these devices. It also explored farmers' knowledge and perceptions of smart farming technologies to gauge their preparedness for adoption.

A multiple-seed snowball sampling approach was utilized to overcome potential biases and ensure diverse representation. This method involved identifying initial participants who met the study criteria and then asking them to refer other relevant individuals, creating a chain of referrals [15]. This approach helped reach a broad spectrum of farmers, including those who might otherwise be underrepresented, such as those in remote areas or with varying technology access.

Depending on internet availability, data was collected through face-to-face interviews and online platforms [16]. The survey utilized structured questionnaires with closed and open-ended questions, allowing for comprehensive quantitative and qualitative analysis. This methodology ensured that the data collected covered various factors influencing smart farming preparedness, including technology usage patterns, device comfort levels, and overall readiness to adopt smart farming technologies.

The collected data was analyzed to identify patterns and gaps in smart farming preparedness among Kenyan farmers. The findings provided insights into technology adoption and readiness, highlighting areas where further support and development are needed to enhance preparedness for smart farming [17].

FINDINGS

The study presents a comprehensive overview of smart farming technology adoption among Kenyan farmers, focusing on ICT device usage, comfort levels, internet access modes, and familiarity with smart farming benefits.

ICT Device Ownership

The data reveals a clear preference for smartphones and laptops, with ownership rates of 45.0% and 38.3%, respectively. These devices are integral to modern farming activities due to their mobility and computing capabilities. Conversely, tablets and desktops have lower ownership rates, suggesting that mobility and flexibility are more valued in agriculture. The high frequency of smartphone use (40.5%) and significant laptop use (16.8%) further confirms their central role in daily farming operations. The comfort levels reported with smartphones (86.8%) and laptops (83.5%) indicated high acceptance. In contrast, the lower comfort levels of tablets and desktops suggest usability challenges that may hinder their adoption.

Table I: ICT Device Ownership

ICT Device	N	Per cent
Smartphone	326	45.0%
Tablet	55	7.6%
Laptop	278	38.3%
Desktop	66	9.1%
Total	725	100.0%

Device Comfort and Usage Patterns

The comfort levels with different devices further emphasize the prominence of smartphones and laptops. 86.8% of respondents reported being very comfortable with smartphones, compared to 83.5% for laptops. In contrast, only 53.8% of respondents felt very comfortable with desktops and tablets. The varying comfort levels highlight the need for device-specific improvements to enhance user experience, particularly for less favoured devices like desktops and tablets.

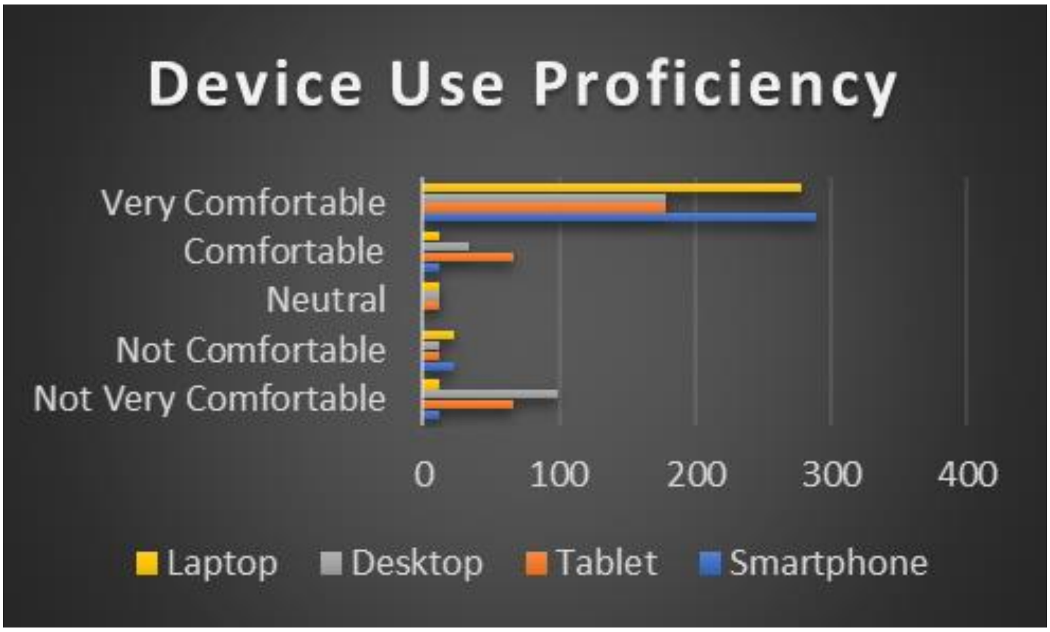

Fig 1: Device Usage Proficiency

Internet Access Modes

Most respondents (70.3%) use home internet as their primary mode of access, highlighting the critical role of stable home internet connections in supporting the adoption and use of smart farming technologies. The reliance on office internet (23.1%) and minimal use of cyber internet (6.6%) underscores the importance of home internet infrastructure in ensuring continuous connectivity, which is essential for technology-driven farming practices.

Table II: Internet Access Modes

Internet Access Mode		Frequency	Per cent
Valid	Home Internet	234	70.3
	Office Internet	77	23.1
	Cyber Internet	22	6.6
	Total	**333**	**100.0**

Familiarity with Smart Farming Benefits

The survey assessed respondents' familiarity with several benefits of smart farming technologies. Increased Crop Yield was the least familiar benefit, with 50.2% of respondents remaining neutral and only 30.0% reporting familiarity. While the potential for increased crop yield is recognized, it may not be the most prominent or well-understood advantage among farmers. On the other hand, Improved Water Management emerged as a benefit with notable recognition; 46.5% of respondents were familiar with this advantage, and an additional 20.1% were very familiar. This high level of awareness highlights the importance of water management in agricultural contexts, particularly in regions where water resources are a critical concern. Improved Soil Health Monitoring also garnered significant attention, with 33.6% of respondents reporting familiarity and 23.1% being very familiar. This suggests that while there is some recognition of the benefits of monitoring soil health, it may still be an emerging concept for some respondents. In contrast, Better Decision Making was highly acknowledged, with 73.5% of respondents being familiar or very familiar with this benefit. This high level of familiarity reflects the perceived value of data-driven decision-making in enhancing farm management practices. Similarly, Reduced Labor Cost was recognized by 40.2% of respondents as very familiar and 26.7% as familiar, underscoring its impact on operational efficiency and cost reduction. Overall, these findings reveal a varied level of understanding regarding the benefits of smart farming technologies, indicating the need for targeted educational initiatives to address gaps in knowledge and promote comprehensive adoption of these technologies.

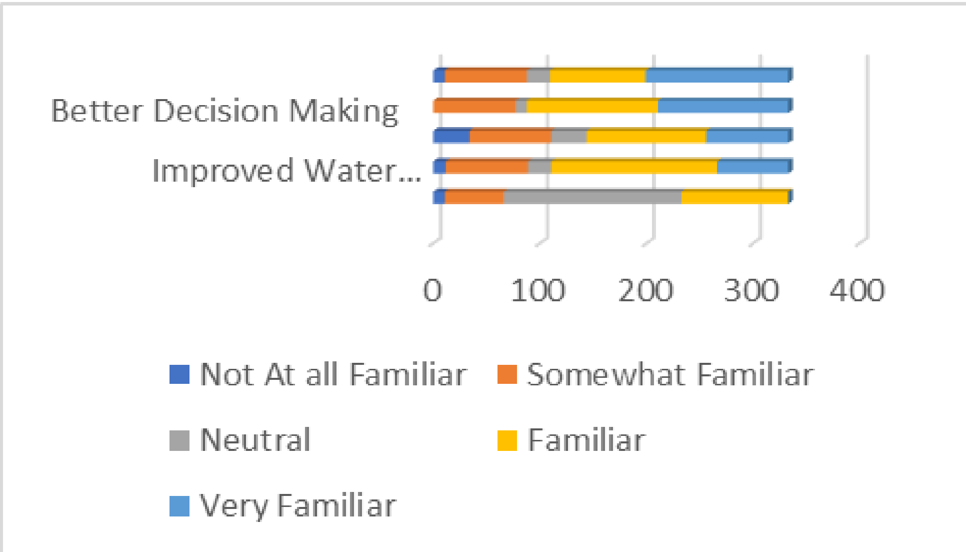

Fig 2: Smart Farming Technologies Benefits

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Socio-economic Factors Influence on Technology Adoption

Table III: Socio-Economic Factors

Socio-Economic Factors	**N**	**%**
Access to infrastructure	83	25
Income level	67	20
Education level	50	15
Government policies and regulations	33	10
Occupation	3	1
Geographic location	10	3
Age	37	11
Gender	17	5
Cultural background	13	4
Social norms and attitudes towards technology	20	6
Total	333	100

The study sought to establish how socio-economic factors influenced technology adoption in smart farming. The results indicate that access to infrastructure (internet, electricity) is the most crucial factor, with 25% of respondents identifying it as a major influence. Following this, income level impacts 20% of respondents, while education level affects 15%. Government policies and regulations are considered significant by 10%, whereas occupation (1%), geographic location (3%), age (11%), gender (5%), cultural background (4%), and social norms and attitudes (6%) have lesser influence. These findings highlight that improving infrastructure, income, and education should be prioritized to enhance technology adoption in smart farming.

DISCUSSION

The findings underscore the essential role of smartphones and laptops in adopting smart farming technologies, reflecting their mobility and computing power. The high comfort levels with these devices and the predominant home internet use highlight the importance of reliable and accessible technology infrastructure in supporting smart farming practices. Additionally, the socio-economic factors further elucidate the context: access to infrastructure is seen as the most influential factor, impacting 25% of respondents, followed by income (20%) and education (15%). These factors are crucial in understanding the adoption dynamics.

However, varying familiarity with smart farming benefits suggests targeted educational initiatives are needed. While benefits like improved decision-making and reduced labour costs are well-recognized, there is a need to enhance awareness of other advantages, such as increased crop yield and better soil health monitoring. Addressing these knowledge gaps through focused educational programs, particularly those tailored to varying income levels and educational backgrounds, could boost understanding and adoption.

Moreover, improving infrastructure and making devices more accessible can support technology adoption. Efforts to enhance the usability of less favoured devices, alongside improving socio-economic conditions, could significantly enhance the adoption and effective use of smart farming technologies, ultimately contributing to increased agricultural productivity and efficiency.

CONCLUSION

The study provides valuable insights into the current state of adoption of smart farming technology among Kenyan farmers, highlighting key aspects such as ICT device usage, comfort levels, internet access modes, and familiarity with the benefits of these technologies. The findings reveal a clear preference for smartphones and laptops, which are integral to daily farming operations due to their mobility and versatility. This is supported by high comfort levels with these devices, underscoring their essential role in adopting smart farming practices.

The study also emphasizes the critical role of home internet access, which is predominantly used by farmers and is crucial for effectively implementing smart farming technologies. Socio-economic factors further illuminate the context, showing that access to infrastructure (25%) and income level (20%) are the most significant influences on technology adoption. These factors highlight the importance of reliable technology infrastructure and financial capacity in supporting smart farming practices.

Despite this, there is a noticeable disparity in familiarity with various benefits of smart farming technologies. While some advantages, such as better decision-making and reduced labour costs, are well-recognized, others, like increased crop yield and improved soil health monitoring, require more emphasis. This suggests a need for targeted educational programs that address knowledge gaps, particularly in areas where socio-economic conditions such as education level and income may influence awareness and adoption.

Overall, the research underscores the importance of addressing these knowledge gaps and improving the usability of less favoured devices to enhance the adoption and effective use of smart farming technologies. By developing strategies that tackle technological and socio-economic barriers, stakeholders can better support farmers in leveraging these innovations to improve agricultural productivity and sustainability.

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BIOGRAPHY

Dennis Gichuki is a PhD candidate in Information Technology at Kibabii University with a focus on the integration of Wireless Sensor Networks (WSN) and Machine Learning (ML) for smart farming technologies in Kenya. His research aims to enhance sustainable farming practices through the development of advanced machine-learning algorithms that utilize real-time data from WSNs. He is a member of the Association of Computing Practitioners-Kenya and the Internet Society. He has a keen interest in systems virtualization, ML, and Information and Communication Technology for Development (ICT4D). Committed to leveraging technology to address agricultural challenges, improve crop yields, and promote sustainable development.

Prof. Samwel Mungai Mbuguah is an Associate Professor of Information Technology and the Director of Planning and Organization Performance at Kibabii University. He has previously held roles such as Director of Information and Communication Technology and Acting Dean of the School of Computing and Informatics at Kibabii University. With a PhD in Information Technology, Prof. Mbuguah has supervised seven PhD students and seventeen Master's students to graduation, assessed 54 postgraduate theses from various universities, and published 70 papers in refereed journals, books, and book chapters. He is a Chartered Engineer and an assessor for Chartered Engineer applicants for the Engineering Council UK. Additionally, he is a professional member of the Association of Computing Machinery, the British Computer Society, and the Association of Computing Professionals in Kenya.

Dr. Patrick Oduor Owoche, with a PhD in Information Technology from Kibabii University, is a distinguished academic and IT professional known for his contributions to educational leadership and technological innovation. He has played a crucial role in promoting international collaborations and enhancing Kibabii University's global footprint through strategic partnerships. His technical expertise includes web and multimedia technologies, instructional design, and cloud application development. His active participation in seminars and workshops, including those at Leibniz Universität Hannover and Stellenbosch University, along with his role as a Visiting Scholar at Chandigarh University, highlights his dedication to academic excellence. His research focuses on applying information technology in educational settings to improve teaching methodologies and infrastructure. Beyond academia, he contributes to professional bodies and policy development in technology-enabled learning and international education strategies, impacting global educational practices and innovations.

Paul Oduor Oyile is a Tutorial Fellow and PhD in Information Technology student at Kibabii University, deeply intrigued by Artificial Intelligence (AI). His current focus is on harnessing AI in Education, Agriculture and Health.