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IoT appropriation for crop management and productivity enhancement in South Africa

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Background: While the Internet of things (IoT) has been praised for its potential to improve food security and combat climate change, it is unclear how agricultural entrepreneurs (especially farmers) in emerging contexts are harnessing this technology to leverage agricultural productivity.

Objectives: Given the lack of documentation of novel-technology-supported farming approaches in relevant extant literature in emerging economies, this study sought to explore how South African farmers are harnessing the strength of IoT to leverage productivity in crop farming.

Method: To address this research gap, a systematic literature review was conducted to establish how IoT was implemented in crop farming in resource-constrained contexts of South Africa. These databases, namely Google Scholar, Scopus, MDPI, IEEE Xplore, and Science Direct, were utilised to gather the relevant information.

Results: The findings highlighted that IoT technology presented multiple opportunities for improving operational efficiency and connectivity and facilitating remote management of agricultural activities. Conversely, the findings suggested that the utilisation of IoT in crop farming poses serious challenges arising from software complexity, data security, lack of supporting infrastructure and technical skills.

Conclusion: This article demonstrates how institutional voids, human capital and technological gaps in the South African farming industry undermine crop farming, food security in the communities and government efforts at promoting the latest technologies for leveraging agricultural productivity and the farming industry in general.

Contribution: The study has contributed to filling the gap in the IoT literature in South Africa and worldwide. This study also contributed by aligning the theory to the study.

Keywords: agriculture productivity; climate change; food insecurity; crop farming; IoT technologies; crop management; South Africa.

Introduction

The Internet of things (IoT) comprises various devices and technologies, such as sensors, radio frequency identification (RFID) technology, global positioning systems (GPS), infrared sensors, laser scanners and gas sensors that are used to identify things and gather and process information (Ma, Dai & Ding 2022). These technologies and devices have the potential to collect information and feedback from any object at any given instant or location. In addition, IoT devices and technologies possess the capacity to actively monitor, establish connections and participate in real-time communication while collecting various types of data such as sound, light, heat, energy, mechanics, chemistry, biology and geography. In essence, IoT has shown that it will offer significant benefits to crop farming through its capacity to deploy innovative technologies in diverse fields (Farooq et al. 2020). The implementation of the IoT has brought changes to the traditional approach employed in the crop farming industry (Venkatesan & Tamilvanan 2017). The reviewed literature suggests that the crop farming industry is confronted with multiple challenges spanning ineffective human interaction, and high costs of labour, power and water consumption (Chidambaram & Upadhyaya 2017). The benefits of modern technology have not been fully harnessed to address these hurdles. Therefore, despite the multiple affordances presented by digital technologies for business process integration and information integration (Marcinkevicius & Vilkas 2022), it is not surprising that the crop farming industry remains untransformed and not fully automated (Kumar et al. 2017; Sagar et al. 2017). As developing countries and their people are continually confronted with perennial challenges, such as persistent droughts, unhealthy food consumption practices, malnutrition and starvation, many scholars (Ngcamu & Chari 2020) have posed crucial questions regarding how the affordances of new digital technologies can be harnessed to address the agricultural productivity gaps, especially on the African continent. For instance, farming automated systems have been proposed as panaceas to some of these persistent productivity-related challenges (Rau et al. 2017; Sankar et al. 2017).

Despite the lack of a clear winning formula on how to apply these technologies, there is growing consensus in literature (Soeker, Lusinga & Chigona 2021) that the affordances and capabilities of IoT present fundamental opportunities for addressing Africa's productivity hurdles. For instance, IoT-based technologies have been touted as a solution to the crop farming problem (Soeker et al. 2021) and present new possibilities for supporting innovations in the crop farming industry. Yet the large body of research into the efficacy of IoT-based technology in agricultural operations in recent years (Madushanki et al. 2019) does not seem to adequately account for the specific ways such technology has been applied in emerging economies' contexts (Soeker et al. 2021). To further compound this challenge, there has been stiff resistance to abandoning traditional farming methods in favour of mechanisation and automation in some parts of the developing world because of the productivity paradox, popularly known as the Solow paradox. This paradox describes the lack of a corresponding increase in productivity growth despite significant investments in information technology. As such, contrary to the huge promises regarding the ability of technologies to promote food security by improving data accuracy, enhancing the agility of production processes, improving the reliability of energy consumption, supporting distribution chains and facilitating the commercialisation of production (Soeker et al. 2021), the huge costs of technologically related agricultural operations and activities have prevented farmers in developing economies from investing in such technologies, especially when improvements in productivity and profit margins are not guaranteed.

In a context characterised by growing food insecurity and undernourishment of the young population of South Africa occasioned by climate changes, such as low rainfall patterns, heatwaves, drought and intense storms and the need to combat poor crop management practices and declining agricultural productivity is non-negotiable. Therefore, this study firstly contributes to addressing the extensive agricultural productivity challenge (Dlodlo & Kalezhi 2015) and growing food insecurity, coupled with greater concerns about South Africa's incapacity to transform nutritional standards (Soeker et al. 2021) in the wake of a rapidly expanding population that present a complex dilemma for both farmers and policymakers. Most South African crop farmers have been severely affected by adverse weather conditions in recent years (Soeker et al. 2021) as manifested in drought and climate change. Despite South Africa's attempts at diversifying to other sectors (e.g. mining, energy, retail and manufacturing) and focussing on industrial activities, its dependence on agriculture implies that this sector still constitutes the mainstay of the economy. Therefore, negative weather elements present an existential threat to crop farming and agricultural production in South Africa, which is conceived as the agricultural powerhouse of the Southern African region (Food and Agriculture Organization of the United Nations 2015). Consistent with this body of research, the following questions were posed in this study:

1. How have IoT technologies been appropriated to enhance crop management in South Africa?
2. How effective are these technologies in increasing productivity in under-resourced farming communities?

Based on the aforesaid information relating to crop farming in South Africa, there is a great need to improve agricultural productivity to meet current and future agricultural demands. In response to these challenges and given the capacity of IoT technologies to improve operations and enable effective and efficient production, some South African crop farmers have been compelled to invest in IoT technologies. The reason for this practice is that IoT technologies are deemed to possess efficiencies and capabilities that will increase the quality of production and crop yields in South Africa (Prettner & Strulity 2020). Moreover, the IoT enables the practical preparation and implementation of various applications and the upgrading of technologies that, as already indicated, work to improve the quality of crops (Mtshali & Jili 2022), increasing the prospects of enhanced crop production and higher yields.

Secondly, this study contributes to contemporary literature that discusses how emerging disruptive technologies can be harnessed in marginalised farming communities to improve their depth of inclusion in mainstream economic activities (Gatzweiler & Joachin 2016). As such, this literature explains how disruptive innovation can leverage marginalised communities to participate in mainstream economies by availing the resources (e.g. rain, water, humidity, soil temperature and moisture) needed to enhance quality production and improve crop yields (Bailey-Serres et al. 2019; Parker et al. 2019).

Thirdly, this study demonstrates at an empirical level how new technologies can provide some practical solutions to global challenges, such as hunger, malnutrition and starvation, and alleviate poverty in marginalised communities through the use of IoT technologies (Gatzweiler & Joachin 2016). This study demonstrates how adopting a 'grant challenges' approach for addressing global problems necessitates a socio-technical stance that interrogates the benefits and challenges of the implementation of IoT in the crop farming industry, while also accommodating the situated contexts in which such technologies are adopted. This exploration aims to improve the understanding of IoT technologies that can be utilised to support crop farming business processes.

The structure of the article is as follows: the 'Theoretical development' section discusses the diffusion of innovation theory used in this study, followed by the research methodology and results. Thereafter, the article presents a discussion of the study's findings and their implications as well as its limitations and the conclusion.

Theoretical development

Diffusion of innovation theory

The diffusion of innovation (DOI)) theory provides a useful framework for innovation users and non-adopters to familiarise themselves with available new technologies including the invaluable capabilities necessary to make effective use of innovation systems. These innovation systems can take multiple forms ranging from new products, processes to the application of new technologies in various business ventures (Singh et al. 2020). This theory provides heuristic explanations for why certain innovations are rapidly adopted at a massive scale while some other innovations are not adopted at all and wane off. The DOI theory identifies and explains the four components that make the adoption of innovation such as new technologies and new production processes tenable namely: innovation, communication channels, time and social system (Rogers 1995). The innovation denotes the nature of the innovation in terms of usability, trialability, originality and novelty. Despite its novelty and originality, an innovation that adopters find complex and difficult to use in their context can generate limited tractions in terms of its proclivity to adoption. The communication channels describe the conduits through which the innovation is transmitted. Because technology innovations require simple, available and uncomplicated mediums for their uptake and domestication, the use of complex and unconventional means for transmitting the technology has the potential to limit the wide-scale rollout of veritable innovations. Time describes the duration of transmitting the innovation from the innovator to the recipients of the innovation. While certain technologies constitute useful innovations for increased agricultural production, the use of invisible and unconventional means may extend the duration of adoption of certain technologies as it would take ages for adopters to familiarise themselves with the innovation. The social system describes the socio-technical milieu in which the innovation is implemented, thrives or is disrupted. In the South African context where there is a relatively high internet penetration rate compared to other African countries coupled with a fairly developed digital infrastructure, the use of IoT in agriculture would be expected to be comparatively entrenched compared to other African countries.

The DOI theory postulates the three points at which time becomes a significant factor in the innovation process, (1) innovation-decision process (knowledge, persuasion, decision, implementation and confirmation); (2) innovation of individual (innovators, early adopter, early majority, late majority and laggards) and (3) an innovator rate of adoption in a system (Rogers 1995). Following this logic, one discerns that the innovation-decision process is not automatic but rather a deliberate and conscious activity requiring high-intensity psychological functioning of the inventor and his or her interaction with adopters of his or her technology in their context of engagement (e.g. agricultural activities). At best, the process requires continual negotiation and social construction of the innovation in context, evaluating its merits and vices to accommodate divergent views – from the mental construction and distillation of the innovation in the inventor's mind to its acknowledgement and acceptance by users. The innovation of the individual captures the different socio-technological dispositions and motivations of various users of the innovation in the innovation chain – from technology enthusiasts to those who resist the use of technology.

While the processual approach adopted by the DOI theory is useful for demonstrating that technology adoption is not a once-off event but rather entails a chain of interconnected, mutually reinforcing processes and activities, the theory is not without its limitations. For instance, the theory seems to present a sequential and incremental view of technology adoption where a certain phase predates another, without which the successive stage becomes difficult to achieve. While it is logical to expect knowledge to predate persuasion, the sequential materialisation of stages is not sufficiently empirically grounded as it is possible for conjoined stages to materialise and later stages to be realised while evaluating previous stages (Atkin, Hunt & Lin 2015). Therefore, despite its revelatory stance relating to DOI, it may be incapable of explaining how technology adoption explains the conception and materialisation of inter-dependent and conjoined stages of business model innovations (e.g. value proposition, creation and capture) as experienced in agricultural operations.

Research methodology

Given the fragmentation and emergent nature of extant literature on the use of emerging technologies to support crop farming in developing economies (Chenniappan et al. 2022; Dhanaraju et al. 2022), a systematic literature review (SLR) provided an appropriate research method. Such a review is deemed ideal when the researcher seeks to develop a broad perspective on the state of the art of existing literature (Gomez-Chabla et al. 2019) regarding concepts or phenomena under study. The reviewed literature (Rejeb et al. 2022) highlights the lack of clarity on the mechanisms through which farmers in emerging markets are harnessing IoT technologies to support specific agricultural operations, and hard evidence on best-case examples of leveraging such technologies is yet to emerge in these contexts. As such, these findings illuminate researchers' understanding of how agricultural entrepreneurs have harnessed IoT technologies to enhance crop management and productivity and how effectively they have increased productivity in under-resourced farming communities (Plastra et al. 2023; Polymen et al. 2023). The major challenge in the applications of IoT technologies is the fragmentation in the adoption of the systems (Farooq et al. 2020). It is reported that applications of IoT technologies are mainly utilised by the farmers who adopted and still focus on basic functionalities at a high granularity level. There are various opportunities for the application of IoT technology in the crop farming industry: to reduce the number of workers in business ventures, improve crop productivity and reduce crop waste (Singh et al. 2020).

In conducting the SLR the methodology proposed by Keele (2016) served as a guiding framework, to increase transparency in the steps undertaken, promote impartiality in the context of information selection, and allow for the reproducibility of research processes and justification for the conclusions drawn. The conduct of an SLR allowed the researchers to summarise the existing evidence, identify any gaps in current research to suggest areas for further investigation and provide a framework for the appropriate positioning of new research activities (Kitchnham & Charers 2007).

Search strategy

This phase of the SLR involves searching for relevant studies on the research topic. A search string is defined and then used to gather published articles related to the research topic. The authors conducted a search based on the specific keywords and decided to use the 'IoT-based technologies', 'crop farming', 'agricultural productivity' and 'developing countries' search string. An Internet search was performed to collect information. Google Scholar, Scopus, MDPI, IEEE Xplore and Science Direct were used as the main databases for the collection of relevant information. These databases were selected based on the scientific merit of their publications as they often aggregated peer-reviewed scientific works. To ensure a comprehensive search, all relevant sources were tabulated in an Excel Spreadsheet to ensure sufficient coverage based on words searched and the year of publication of searched material. Some additional search phrases such as 'disruptive technologies', 'agricultural production' and 'emerging economies' were also considered to provide more comprehensive search outcomes. Finally, the search string was built by combining the aforementioned keywords with the connectors. The search chain that was used is presented in Table 1.

Keywording using abstract

To locate the relevant articles through keywords used in the abstract, a framework formulated by (Petersen et al. 2008) was used. This framework requires that the search for keywords be implemented in two phases. In the first phase, the abstract was examined and the concepts and keywords that reflected the contribution of the studies were identified. In the second phase, the authors sought to develop a higher level of understanding based on these keywords by looking for information, such as the key gap identified, the context of the investigation, the research method used, the key findings derived and the implications of findings for theory, policy and practice.

TABLE 1: Keywords and data source used in this literature review.

Source	Search string	Context
IEEE Xplore	Application of IoT, crop farming,	Crop farming
Google Scholar	Crop farming, application of the IoT	Crop farming
Scopus	Application of IoT, crop farming	Crop farming
MDPI	Application of the IoT, crop farming	Crop farming
Science Direct	Application of the IoT, crop farming	Crop farming

IoT, Internet of things.

Study selection

The focus of the study was on the IoT technologies that have been appropriated to enhance crop management and productivity in South Africa, how effective these technologies have been in increasing productivity in under-resourced farming communities and what opportunities and challenges were presented by the exploitation of these technologies in crop farming in emerging economies. The authors realised that some articles did not sufficiently reflect the research objectives, so they were assessed for their own relevance. Following the search process proposed by Dyba and Dingsoyr (2008), the articles were selected based on their titles, and those studies that were irrelevant to the research topic were excluded. For example, the keyword protocol returned articles relevant to IoT in other fields that had different meanings from the IoT technology that is applied in crop farming and these articles were excluded because they were out of the scope of this study. In the second phase of screening, the abstract of each article selected in the first screening phase was read. Furthermore, inclusion and exclusion criteria (as proposed in the 'Inclusion criteria' section) were also used to screen articles.

The study selection procedure involved examining the title and the abstract of the research article. If these two items met the mentioned inclusion criteria listed here, these articles were considered for a thorough reading. To the extent that the research study selection is based on the inclusion and exclusion criteria, the process of including and excluding articles is elaborated in the 'Inclusion criteria' section.

Inclusion criteria

Studies that met the following criteria were included:

1. Primary studies related to the research question.
2. Journal articles closely related to the topic as expressed by the research question.
3. Articles explaining the applications of the IoT in crop farming, especially the mechanisms involved, ways through which such technologies are supporting crop management and how productivity is enhanced by such technologies.
4. Studies that highlighted the context in which the research was conducted.
5. The article's full text was available.
6. Study published between 2015 and 2022. This coverage was deemed important because it demonstrates the emergence, development and peak of IoT usage in emerging countries' contexts (Farooq et al. 2020).

Exclusion criteria

The following articles were excluded:

1. Duplicate copies of the same research study.
2. Articles that did not contain any characterisations or descriptions of applications of the IoT in crop farming.

3. Articles that were written in a language other than English.
4. Articles published on company websites that were not peer-reviewed, students' theses and dissertations.
5. Book chapters.
6. Journal articles published before 2015.

The results of the search and selection process are presented in Table 2. Initially, 133 articles were selected when the search protocol was applied to the selected repositories. Subsequently, the screening process was applied based on the keywords, titles, abstracts and full articles of retrieved studies. One author retrieved all these articles and then, the other author checked these articles for possible duplicate titles that were not relevant to the review. For example, most excluded articles were related to the general use of IoT for security, privacy, healthcare, retail and smart cities. Furthermore, after reading the full abstracts of the 83 selected articles in the duplication phase, 53 articles were selected based on their abstracts. Upon further examination, only 33 articles were deemed to be usable. The articles examined were assessed on the basis of having a clearly identified research gap, having a rigorous research method, clear findings, recommendations and implications for future research. Specifically, this process consisted of four phases that are described here. Table 2 presents a summary of the study's selection phases.

Quality assessment

The quality assessment process is extremely important to ensure that the findings of studies are credible, appropriate and can be replicated (Popay et al. 2006; Roberts et al. 2006). Quality assessment is conducted to evaluate the validity of the studies included. It is very important to determine the extent to which validity threats are addressed by the authors. The quality assessment process was performed by checking the articles for their structure – introduction, research method, results and conclusion. The authors sought to secure some answers to the following questions for each article they evaluated:

Introduction: Does the research study's introduction provide an overview of the applications of IoT in crop farming?

Research method: Does the study clearly describe the research methodology?

Results: Does the research study define and specify the study's results? Are the results helpful in finding the answer to the research question?

Conclusion: Does the study accurately report both the positive and negative findings? Does it also report the limitations imposed on the research?

TABLE 2: Primary selection process for retrieved articles.

Phase	Google scholar	Scopus	MDPI	IEEE Xplore	Science direct	Total
1	26	32	12	54	9	133
2	15	21	7	36	4	83
3	10	14	5	2	2	33

The authors' judgment regarding the relevance of the studies was based on the studies' keywords, abstracts, titles and contents relevant to this study's context. The organisation and publication of the research study were also considered. All the peer-reviewed articles were subjected to this quality assessment.

Data extraction strategy

The objective of this stage was to categorise and manage data extracted from the chosen articles. The authors categorised the articles and each one was scanned for relevant information, which eliminated the need to completely read all the studies. The process was undertaken by both authors to provide an independent personal assessment that eliminated subjectivity and instances of bias.

Data extraction strategy: Given the aforementioned data extraction strategy, retrieved data were analysed to address the main research questions and objectives of the study. The reference list for each published article was checked for accuracy and relevance to the phenomena under investigation. The analysis of various research streams was performed to ensure that no important ideas and themes were ignored. The first step was to identify the main concepts such as agriculture productivity, climate change, food insecurity, crop farming, IoT technologies and crop management. Next, during that process of identifying concepts, the title, author, journal, year and supplementary information from each publication were obtained. We assess these concepts for completeness to avoid the potential for bias, considering the study questions, their relevance to the phenomenon under study and the coverage of studies. Attention was devoted to key components of the study such as sample size, duration of observation, industrial sector, company size and key insights.

Thereafter, a qualitative analysis of issues was conducted and the linkages between studies were also considered to avoid duplication of key themes derived. To categorise sources according to specific criteria, the approach developed by Webster and Watson (2002) of classifying each piece of work according to a theme was employed. This approach allows systematic and precise measurable synthesis for coherence and substance. The study also borrowed from Massaro, Dumay and Guthrie (2016) by applying comparison analysis, where authors extract the various and complex strands of thought and compare them. The comparative analysis emphasised, (1) in essence, IoT technologies, looking at how effective these technologies are in agriculture productivity, (2) agriculture productivity, which pertains to the effects of the increase in agriculture productivity arising from the use of these technologies and (3) the contribution to crop management these new technologies provide. The table illustrates the 33 quantitative studies retained in the final sample that were incorporated into the systematic review.

Synthesis: Finally, the findings were summarised in a narrative synthesis.

Ethical considerations

Ethical approval to conduct the study was obtained from the Faculty Research and Innovation Committee, Central University of Technology, Free State (reference no. FMSEC19721).

Results

This review revealed that the IoT technology presented several challenges such as software complexity, a lack of data security, dearth of support infrastructure and technical skills (Pote & Jadhav 2018). It is emphasised that IoT technologies present important opportunities to improve the efficiency of wireless sensors, allow connectivity, and promote operation efficiency and remote management (Khan & Ismai 2017). In this review, the authors collected various published articles that have focussed on the applications of IoT in crop farming in developing countries between 2015 and 2022. Table 3 summarises the studies that were subjected to more in-depth screening and analysis.

Internet of things-based monitoring system

Based on the results of the literature search, the application of IoT in the crop farming industry's topmost area was the IoT-based monitoring system. Internet of things-based monitoring systems comprise various monitoring systems that measure different types of variables such as air monitoring, temperature monitoring, humidity monitoring, soil monitoring, irrigation monitoring, machine learning monitoring, light monitoring, soil moisture monitoring, nutrient level monitoring, soil condition monitoring, fertilisation monitoring, crop disease monitoring, quantity and quantity monitoring and water monitoring (Farooq et al. 2020). Internet of things-based monitoring systems in crop farming require various integrated systems such as sensors and networks to operate effectively and enhance productivity in the crop farming industry. The information that has been collected through this system can be saved in the cloud for future data analysis. An intelligent agricultural field monitoring system that monitors soil humidity and temperature was introduced (Ashifuddin Mondal & Rehena 2018). The results indicated that most researchers pay special attention to environmental temperature, humidity, soil moisture and environmental measurements.

Moreover, IoT-based systems for monitoring air, humidity and temperature in agriculture were established. The system offers a real-time microclimate monitoring solution that is based on wireless sensor networks (WSNs). The system

TABLE 3: The number of studies reviewed by the authors.

Reference	Year	Publication channels	Research approaches	Applications domain	Major focus	Sensors and devices	Protocols network type
Markovic et al.	2015	Journal	Proposed architecture	Controlling	IoT technology is used in controlling plant diseases and insect pests	Multiple sensors	Wi-Fi, Ethernet
Martinez et al.	2016	Journal	Platform	Monitoring	A monitoring platform has been proposed for the suitability of FIWARE precision agriculture	Sensors, Gateway	FIWARE/WSN
Wang et al.	2017	Journal	Framework	Monitoring	Discusses the use of the IoT in greenhouse environmental monitoring in the past decade	Various Sensors, soil temperature, air temperature, air humidity, light intensity Lx, Rainfall MM	WSN, ZigBee
Chowdhury & Raghukiran	2017	Journal	Proposed system	Controlling	Reports on how IoT-enabled controller controls sprinkler remotely providing extraordinary solutions to crop products	Microcontroller, Actuators, gateway	Wi-Fi
Li et al.	2017	Journal	Architecture	Tracking	Agricultural product tracing	Gateway	AVR controllers
Gili et al.	2017	Journal	Proposed solution	Monitoring	Proposed a cloud-based information system to deliver agricultural solutions	Soil sensor	WSN
Keswani et al.	2018	Journal	Framework	Controlling	Proposed a solution for the efficient usage of water	Multiple sensors	WSN
Mazon-Plivo et al.	2018	Journal	Architecture	Monitoring	Proposed architecture to monitor multiple agricultural parameters such as temperature, humidity and soil moisture	Multiple sensors	WSN
Elijah et al.	2018	Journal	Ecosystem	Monitoring	Several IoT agricultural benefits and challenges discussed for monitoring air, temperature, humidity and moisture behaviour	Multiple sensors and devices	Wi-Fi, Sigfox, LoRa, NB-IoT, Wi-Fi
Goap et al.	2018	Journal	Proposed system	Monitoring	A smart irrigation system is developed by using open-source technologies and machine learning	Multiple sensors	WSN, HTTP, Wi-Fi
Gonzalez-Amarillo et al.	2018	Journal	Model	Tracking	Developed a tracking and record-keeping model that traces the growth level of plants in a greenhouse	Multiple sensors, and Raspberry Pi 3	Wi-Fi
Muangpra-thub et al.	2019	Journal	Architecture	Monitoring	Developed an agricultural watering system based on WSN	Temperature and humidity Node MCU	WSN
Chen et al.	2019	Journal	Platform	Controlling	Proposed a low-cost agri-talk IoT-based platform for precision farming, especially soil cultivation	Soil and insects' sensors, actuators	Network, time, protocol (NTP)
Dos Santos et al.	2019	Journal	Model	Monitoring	Proposed model to measure the crop productivity and resolve problems that are anticipated	Multiple sensors	LoRa, WNS, ZigBee, Wi-Fi, GPRS, Raspberry P1 3
Madushanki et al.	2019	Journal	Proposed system	Monitoring	Presents an IoT-based water management system that collects environmental attributes such as temperature, water level and humidity through the sensors and provides accurate irrigation timing	Various sensors	ZigBee, Wi-Fi, Bluetooth
Farooq et al.	2020	Journal	Proposed system	Monitoring	Discusses how IoT can be deployed in agriculture as the ideal solution to address the need for continuous monitoring	Soil moisture, temperature, and humidity sensor/ micro-controller	GPS, WSN, Bluetooth, and ZigBee

Source: Please see the full reference list of the article, for more information

WSN, wireless sensor networks; AVR, Automatic Voltage Regulator; GPRS, general packet radio services; GPS, global positioning systems; HTTP, Hyper Text Transfer Protocol; NB-IoT, NarrowBand-Internet of Things.

comprises a temperature and humidity sensor that is supported by a communication protocol known as ZigBee and is powered by solar panels (Farooq et al. 2020). A wireless sensor network (WSN)-based system can be introduced to monitor the rainfall and water level in irrigation systems in the crop farming industry. This system functions in conjunction with ZigBee and general packet radio services (GPRS) to monitor the growth of a crop plantation. Internet of things technology has the potential to increase crop productivity, prevent attacks from animals and theft (Madushanki et al. 2019), and reduce costs and frequency (Dolci 2017). Internet of things systems are capable of developing systems to frequently monitor plants' soil moisture and increase the number of sensors (Ezhilazhahi & Bhuvaneswar 2017). The IoT systems have the potential to implement a system that can monitor the growth of plants without disturbing them. From the given summary, it is obvious that IoT technologies are capable of performing various tasks in the crop farming industry.

Internet of things-based controlling system

The IoT-based controlling systems comprise different types of variables such as pest control, climate control, soil cultivation control, water control, plant control, disease control, fertiliser control, insect control and illumination control (Farooq et al. 2020). Furthermore, IoT-based controlling systems in crop farming are used to monitor resources such as the environment of farmers and greenhouses, irrigation and water quality. The system has been used to maintain optimal growing conditions so that high-quality crops on farms can grow well. A control system can be developed in conjunction with IoT technology for crop production and management (Markovic et al. 2015). A control system is used to collect and monitor data using autonomous sensor devices and control the actuators. This system utilises various sensors in conjunction with FIWARE. An autonomous sprinkler system can be developed that operates based on the real water content of the soil (Chowdhury & Raghukiran 2017). In addition, IoT functions can be applied to the autonomous sprinkler to prevent excessive water use and plant death by controlling the sprinklers remotely from anywhere in the world based on weather forecasting. The IoT-based controlling system is among the most important mainstream application domains in the crop farming industry.

Internet of things-based tracking system

The IoT-based tracking systems comprise various tracking systems that measure different types of variables such as tracking the growth level of the plants in a greenhouse transportation tracking, storage tracking and record-keeping tracking (Farooq et al. 2020). Internet of things-based tracking systems require various integrated systems such as sensors and networks to operate effectively in the crop farming industry (Shi et al. 2019). An et al. (2019) developed an IoT architecture for tracking systems in the crop farming industry. This tracking system works with various sensors such as RFID, video recording sensors, WNS, Wi-Fi and ethernet for the transition of data. The IoT-based tracking systems have different application service platforms for data processing, analysis and visualisation. Li et al. (2017) introduced a tracking system for pre-packaged food covering the whole supply chain. The system tracks the movement of products within the workstation before and during dispatch processes.

Internet of things protocol network and sensors

The authors have categorised all technologies utilised in this article. This study has identified Wi-Fi as the most used IoT technology in the crop farming industry. The results showed that mobile technology is used as a tool in the crop farming industry less frequently than Wi-Fi. The last IoT technology that has been utilised in crop farming is ZigBee to transfer data. Internet of things utilises various hardware devices such as laptops, smartphones, computers, network cards, wireless sensors, multiple sensors and RFID tags, while software utilises client-side software, middleware and server-side software (Krotov 2017).

Discussion

In this article, the authors have identified important attributes to analyse the research findings related to the use of IoT technologies in the crop farming industry. Data from 33 recent scientific articles have been collected and analysed. It is important to mention that the South African crop farming industry heavily depends on farming equipment, labour and infrastructure to survive. The review results show that IoT technologies have made human life much easier and faster for certain sections of the crop farming industry. The results show that IoT technologies utilise interconnected devices to develop solutions with high compatibility (Farooq et al. 2020). The IoT has gradually changed the techniques employed for monitoring crops and plants. Crops and plants can be monitored with various devices with different parameters to ensure their healthy and stable growth. Some crop farmers use IoT technologies to address the need for monitoring the environment around the crops (Farooq et al. 2020) while others developed an intelligent and low-cost irrigation monitoring system. The study results showed that monitoring systems utilise environmental temperature, together with humidity and soil moisture. Moreover, IoT technologies operate in conjunction with various other systems, such as sensors, Wi-Fi, ZigBee, WSN, Lora and Sigfox (Farooq et al. 2020; Madushanki et al. 2019). In essence, Internet of things monitoring systems require different technologies to operate efficiently and effectively in the crop farming industry. The integration of different technologies provides many advantages, such as accurate irrigation timing (Madushanki et al. 2019).

The study results show that IoT technologies especially sensors and Wi-Fi also have been utilised to control damage to crops and plants due to diseases and insect pests (Markovic et al. 2015). Literature highlights that IoT technologies enable the controllers to remotely activate the water sprinklers (Keswani et al. 2018) and thereby provide solutions for efficient water management in the crop farming industry. Internet of things systems such as GPS, Zigbee, Bluetooth and WSN have been instrumental in addressing weather and environmental conditions such as humidity, temperature and soil moisture.

Evidence suggests that the facilitation of tracking of the crop products from the field to their destination has been among the other affordances of IoT technologies. Specifically, they provide a tracking and record-keeping model that traces the growth level of plants in a greenhouse product tracing system (Ganzalez-Amarino et al. 2018). Essentially, such technologies have been instrumental in empowering crop farmers with information on the growth of crops and plants in the greenhouses. Apart from the identification and tracking of farmers in need of transport logistics for their crop products, sensors (e.g. Raspberry Pi 3, Wi-Fi and gateway) can also track and trace crop production to the benefit of farmers (Li et al. 2017).

The results show that the IoT protocol network and sensors have been used in the crop farming industry to support IoT systems. Wireless sensor network technology has been used to increase crop production to meet the growing needs of the increasing population in developing countries (Madushanki et al. 2019). In emerging economies with limited Internet access and speed, the other IoT technologies utilised include low-power Wi-Fi, short-range IoT networks, low-rate wireless PAN (LoraWAN), or low-power and wide-area networks (Farooq et al. 2020). Other IoT technologies used include WSN deployed in various IoT applications such as monitoring and controlling environments. Zigbee has been used to tackle drought and arid conditions to prevent the loss of crops and monitor climate conditions. Evidence from the literature suggests that Wi-Fi and Raspberry Pi play an important role in improving the crop's traceability and increasing overall yields (Ganzale-Amarino et al. 2018) as well as reducing wastage of crops and water use.

The study results show that the major challenges faced by the South African crop farming industry relate to optimising the accessibility of resources such as seeds, fertilisers and suitable cultivars, management techniques and expertise in crop farming processes and applications (Soeker et al. 2021). In essence IoT in crop farming has the potential and capability to address these aforementioned challenges. Moreover, IoT technologies have the potential to increase productivity and sustainability (Ammad-Uddin et al. 2019; Ayaz et al. 2019). Some major challenges pertaining to the use of IoT technologies are the accessibility of IoT, the organisation of Internet access and the integration of IoT sensor technology (Kavitha & Rao 2020; Nayak, Kavitha & Rao 2020). The lack of IoT access affects both the South African commercial and subsistence crop farmers (Ayaz et al. 2019). These aforementioned challenges lead to delays in the implementation of IoT in the crop farming industry, although, commercial farmers have implemented applications of IoT in crop farming. The advantage that commercial farmers have over subsistence farming is that they use high-technology equipment in their crop farming industry. The lower level of subsistence farmers reduces the chances of adopting applications of IoT in their farming systems (Soeker et al. 2021). The lack of technological infrastructure is the greatest problem facing South African crop farming because most small farming practices occur in rural areas throughout South Africa. Some IoT technologies cannot function without the support of an Internet connection. The crop farming industry's use of IoT technology depends on an effective telecommunication infrastructure.

The diffusion of new technology for the improvements of production capabilities necessitates the introduction of creativity, collaboration and the perfection of diverse channels through which communication happens to disseminate innovation. Rogers (1995) examines the subject matter pertaining to communication channels, time and the social system.

The communication channels refer to the diverse methods through which the dissemination of innovation takes place (Rogers 2003). Compared to small emerging farmers, commercial farmers are more oriented to develop more advanced channels for the dissemination of their latest technologies such as IoT as they tend to have a well-developed digital infrastructure, sophisticated manpower trained in the acquisition and deployment of IoT, and a strong finance base to purchase such technologies. In commercial farming communities, the speed, scope and breadth of IoT awareness and deployments are made possible by different communication channels ranging from social media platforms, Internet platforms and websites, and direct implementation of IoT on their farms. Contrastingly, emerging crop farmers may encounter difficulties in embracing and deploying IoT technology because of insufficient technological expertise, inadequate digital infrastructure to support their agricultural activities, restricted information accessibility and low levels of literacy (Shi et al. 2019). These setbacks constrain their capacity to monitor, control and track their crop farming activities such as weather forecasting, planting, weeding, pest control and harvesting drawing on the capabilities of digital innovations and the latest technologies.

According to Rogers (2003), technological innovations come into social systems through various channels and these innovations reduce the level of uncertainty between cause and effect regarding the attainment of outcomes. This means that the social systems comprise different stakeholders who interact with their contextual conditions in shaping preferred outcomes. As such, commercial and emerging farmers interact with their physical infrastructure, climatic conditions, human labour and immediate technological affordances in influencing farm management practices and enhancing productivity. Through communication channels, actors within social systems such as crop farmers can connect with Internet networks and provide targeted support in crop farming activities ranging from land preparation (e.g. ploughing, disking and harrowing), irrigation, plant morphology and nutrition tests, harvesting (sorting, screening, separating and refining) and other activities within the agro-processing value chain. They must also address challenges such as insufficient network infrastructure and limited availability of appropriate devices because of geographical constraints (Shi et al. 2019). The DOI theory emphasises the significance of the time of diffusion, which is the duration needed for an innovation to be transmitted from its creator to the intended recipients (Rogers 1995). The integration of IoT technology in crop farming necessitates a substantial time investment owing to the complexity of the innovation implementation within the crop farming domain. Some crop producers are unable to engage in IoT training because of constraints with the self-management of the agricultural enterprise (Farooq et al. 2020), thereby delaying and extending the duration of implementation. Uncertainty in IoT implementation in crop farming also arises from the lack of clarity on how to implement the technology innovation because of the lack of knowledge and experience in this technology and software.

The social system encompasses the socio-technical environment in which an innovation is situated and this can thrive or experience any form of disruption. The different organisations in the farming communities are differentially positioned to succeed or fail in their absorption and implementation of IoT depending on the social-technical system – the broader ecosystem in which they operate. For instance, the level of competition in technology adoption, the appetite for technology appropriation by users, the financial flows within the ecosystem to support technology uptake and the size of firms are all significant explanatory factors in successful IoT adoption in crop farming. The large size of the company has a bearing on the use of IoT technologies in commercial agriculture (Madushanki et al. 2019), as such firms often have individuals with competence and experience in IoT technology to implement specific farming activities. Compared to emerging crop farming, large-scale farmers often have an information technology (IT) department dedicated to the conduct of research and development, and application of IoT in farming operations ranging from planting, irrigation, pest control, harvesting, storage, logistics and distribution drawing on IoT technologies.

The process of making decisions regarding innovation is not a spontaneous occurrence, but rather a purposeful and mindful endeavour that necessitates the inventor's active and intense psychological functioning, as well as their relationship with individuals who adopt their technology within their specific context of involvement, such as in agricultural operations. Therefore, IoT monitoring systems for assessing air, temperature, humidity, soil, irrigation, machine learning, light, soil moisture, nutrient levels, soil condition, fertilisation, crop disease, quantity and water monitoring (Farooq et al. 2020) demand the interaction of meteorology, research and development, technology department and field operations departments. Moreover, apart from these interactions, the cost and complexity of software, adequacy of the infrastructure for crop cultivation and the sequence of implementation are all critical process considerations that cannot be taken for granted.

According to Farooq et al. (2020), IoT-based control systems encompass various factors such as pest, climate, soil cultivation, water, plants, diseases, fertilisers, insects and illumination controls. Various application service platforms are available for data processing, analysis and visualisation in IoT-based tracking systems. In their study, Li et al. (2017) proposed a comprehensive tracking system for pre-packaged food that encompasses the entire supply chain. Prior to and during dispatch procedures, the system monitors the movement of products within the workstation. The process of innovation decision-making is not inherently automated, but rather a purposeful and mindful endeavour that necessitates the inventor's high-intensity psychological functioning and their contact with technology adopters within their specific context of involvement, such as agricultural operations.

Generally, there are five innovation decision-making processes, namely awareness and planning, selecting, trial, evaluation and implementation (Abrahamson & Rosenkopt 1993). Awareness makes a huge contribution to market priorities, allowing farmers to profit from their crops and planning necessitates farmers to forecast the range of resources, needs and outcomes they anticipate from their activities. Selecting involves identifying the geographical conditions, climatic change and weather conditions that can affect the productivity of the crop farmers (Abrahamson & Rosenkopt 1997). The geographical location of the crop farmers can facilitate or limit the ease of access to transportation and other facilities on the farm. The trial refers to the pilot project that must be performed to limit the risk or failure of the project before the start-up. It also helps to avoid the loss of resources that may occur in crop farming (Rogers 2003). The evaluation involves examining the ways of expanding the adoption of innovation or new technology in crop farming. It also looks at financial resources and resources required for the business venture. The implementation pays special attention to the organisation's performance after the adoption of new technology such as IoT technology (Zilberman 2008).

Study implications

This study has provided the theoretical implications of the reviewed extant literature on the application of IoT in crop farming. These theoretical implications focussed on the disruptive innovation theory. Moreover, crop farmers experience environmental implications such as climate change and water scarcity that pose a huge challenge in terms of the performance and productivity of crop farming. These challenges may increase food prices. Fraser et al. (2016) assert that some food experts, farmers and economists revealed that the 21st century presented a huge challenge to sustainable crop production. The adoption of IoT technologies in crop farming is viewed as one of the best ways to solve the problems caused by environmental implications. There; however, are economic implications that concern the adoption of IoT technologies because this process may create more inequality in the agriculture sector (Bronson & Knezevi 2016). These concerns are the result of the South African agriculture sector's history, which comprises commercial farmers and small-scale farmers. Commercial farmers have an advantage of adopting IoT technologies because of their resources, skills and experience when compared to small-scale farmers. However, it is plausible that the adoption of IoT technologies can increase the inequality between the two groups in the South African agricultural sector. The implications related to the application of IoT technologies in crop farming involve the need to understand these processes and procedures. Internet of things applications can help farm owners and policymakers design new strategies to improve the productivity and sustainability of crop farming (Singh et al. 2020). Farm owners, managers and policymakers should pay special attention to certain applications of IoT for crop farming such as their utilisation as monitoring systems, controlling systems and tracking systems. The implementation of these applications can lead to improved productivity and sustainability in the crop farming industry.

Limitation of research

This study was limited because it focussed on the use of IoT technologies only in the crop farming industry and ignored other agricultural sectors, while various other fields within the agriculture sector may also utilise IoT technologies to improve their productivity and performance. The study focussed on small-scale farmers in crop farming while the South African agriculture sector consists of two types of business ventures, that is, small-scale farmers and commercial farmers. Furthermore, the study focusses on small-scale farmers in crop farming only although all small-scale farmers experience similar problems irrespective of their products and services. The study was limited because it focussed only on farming in South Africa, although the research topic and findings may have applied to other developing countries. Furthermore, the study employed an extensive review of literature as the research method and ignored other research methods such as surveys and case studies that may have provided additional information to that of the literature review. Also, this study did not take into account the fact that IoT technologies continue to change and evolve. However, the authors trust that this review of literature will help academics, agricultural practitioners and technology experts to better understand the role played by IoT technologies in the South African crop farming industry.

Conclusion

This article has identified the potential of applying IoT technologies in the South African crop farming industry to improve productivity and crop management for both rural and urban farming areas. It has demonstrated various benefits of applications of IoT technologies in the crop farming industry. Some of the major applications include water management, weather forecasting, monitoring health conditions, plants and disease management, soil quality and data storage. The study seeks to influence policymakers regarding the adoption of IoT technologies in the South African crop farming industry in both urban and rural areas. The IoT technologies have been developed to support the government's efforts to reduce poverty and improve the standard of living of people involved in the South African crop farming industry. This study selected disruptive innovation theory as a useful lens for adopting IoT technologies in the South African crop farming industry. This theory provides a useful framework for comprehending the adoption of IoT technology to transform the crop farming industry from a traditional to a modern approach. The new technologies have the potential to improve the productivity and management of crops, particularly in commercial farming where radical innovations are easily embraced due to the availability of resources.

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Competing interests

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Authors' contributions

Z.M. wrote the original article. P.R. supervised Z.M. in the writing process and revised several versions of the draft article.

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Data availability

The data that support the findings of this study are available from the corresponding author, Z.M., upon reasonable request.

Disclaimer

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