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A Survey on Digital Agriculture in Five West African Countries

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Abstract: This study focuses on agriculture, which is the main source of economic growth in many West African countries. In recent years, conventional agriculture has undergone a remarkable evolution and digital technologies are widely used for different purposes. While the world is rapidly using advanced digital technologies to grow their agriculture, Africa seems to be lagging behind, especially West Africa. To know how to contribute effectively, it is important to know what is being performed about this issue. The objective of this study is to examine the state of digital agriculture in five countries, namely, Benin, Burkina Faso, Côte d'Ivoire, Ghana, and Nigeria. The study consisted of an analysis of the scientific contributions of these countries and the cases of actual deployment. This is carried out by means of a bibliometric study based on data collected from the Web of Science and a comparative review of the technologies used in the target countries using data from several sources, such as IEEE, Scopus, Science Direct, Google Scholar, etc. The bibliometric analysis based on 3249 publications revealed that research interests have increased significantly since 2014. Climate change, machine learning (ML), and adoption have been the hottest topics of discussion and most of the organizations working on the topic are academic bodies. Moreover, a considerable amount of the scientific input was obtained from Nigeria, which is the most populous of the five countries considered. The survey on digital farming showed that publications in Nigeria that address deployment cases were focused on the internet of things (IoT), wireless sensor networks, blockchain, and artificial intelligence (AI) technologies. In Ghana, practical cases of blockchain, AI, and big data deployment were observed, while Burkina Faso focused on IoT and AI. In Côte d'Ivoire and Benin, the deployment cases generally focused on AI.

Keywords: technologies; innovations; agriculture; artificial intelligence; internet of things; machine learning

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1. Introduction

Digital agriculture is a kind of agriculture, which exploits modern technologies to gain sustainable development in agriculture fields, such as crop production, soil monitoring, livestock production and management, and fisheries. The agriculture sector is a development sector contributing to a large part of developing countries' gross domestic product (GDP). Following the statistical predictions highlighted in [1], the worldwide population will reach 8 billion by 2023 and nearly 10 billion by 2050. Therefore, the digital transformation of agriculture is unavoidable to meet food security requirements faced by worldwide countries in general and emerging countries in particular.

Many technologies are used in numeric agriculture. We can quote the internet of things (IoT), geographical information system (GIS), big data, artificial intelligence, wireless sensor networks (WSNs), and blockchain. All of these technologies have a specific and useful application in digital agriculture. Furthermore, they are sometimes jointly used to solve many problems that analogue agriculture induces. A considerable amount of research has previously been performed on these technologies [2]. While some researches discuss real application cases of some technologies, others present a bibliometric analysis of one or two technologies in Africa. To the best of our knowledge, a gap in the scientific literature exists regarding a review of technologies used in digital agriculture in West African countries.

What is the scientific research contribution of each of these countries?

Which institutions have carried out the most work on the subject?

What are the most reliable sources to find the right information on the subject?

What is really being carried out in terms of digital agriculture deployment in each country?

To answer these questions, this paper presents a bibliometric study of digital technologies in agriculture and a literature review on these technologies to help researchers, government members, and farmers in the growing sector. To achieve this work, related works are first presented on bibliometric study and technology inventory, followed by the methodology adopted to perform this work. Then, the bibliometric study presentation and the technologies' review are presented. Thereafter, the main contribution of this work, and the discussions and conclusions finalize the paper.

2. Materials and Methods

2.1. Bibliometric Survey on Digital Agriculture

In the literature, many research papers have addressed bibliometric studies focusing on digital innovations and technologies in agriculture [3]. In [4], the authors developed a literature review on the relationship between the IoT and agriculture from 2012 to 2019. Through this study, they have shown the growing interest in the IoT for agriculture-related applications. A literature review is also carried out to show the contribution of the IoT to food production [5]. In ref. [6], a literature review was conducted on artificial intelligence and agriculture. To explore research on technology adoption in agriculture and understand the determinants of technology adoption using models, such as the technology acceptance model, a bibliometric analysis was conducted [7]. Annas et al. [8] conducted a literature review on digital innovation, data analysis, and resilience chain. In [9], Alireza Abdollahi et al. carried out a literature review on sensor networks in agriculture from 2020 to 2021. In [10], through a systematic review, research contributions on digitalization and big data in agriculture were explored, and in [11], research on UAV and precision agriculture was assessed. However, today, digital technologies, such as blockchain have demonstrated their ability to create visibility and transparency across the supply chain through the digitally distributed ledger, smart contracts, and multilayered protection against financial threats [12,13]. While big data analytics is found to be useful in enhancing data processing capacity, and thereby, responding to disruptive events [14,15]. Moreover, while literature reviews have shown the contribution of IoT, it is difficult to state concretely, when talking about digital agriculture, which technologies are most used in the publications and how and where they are most used. Amongst the important research, it is noted that very little literature has carried out a systematic comparative review of the contribution of different digital technologies in the field. Therefore, this study first relies on bibliometric analysis as an ideal method to examine the current knowledge base underpinning digital agriculture in the five target countries.

2.2. Survey on Technologies Used in Digital Agriculture

In 2019, the application of precision agriculture has been investigated [16]. Precision agriculture defines a management strategy that gathers, processes, and analyzes temporal, spatial, and individual data and associates it with other data to support management decisions according to the estimated variability for improved resource use efficiency, productivity, quality, profitability, and sustainability of agricultural production [17]. It exploits sensors and software to ensure that the crops receive exactly what they need to optimize productivity and sustainability. In this work, IoT and WSN applications were highlighted. The focus is on wireless communication technologies, sensors, and wireless nodes used to assess the environmental behavior, the platforms used to obtain spectral images of crops, the common vegetation indices used to analyze spectral images, and applications of WSN in agriculture were highlighted. The main farming parameters used in precision agriculture development are crops, i.e., soil nutrients, the soil's water level, wind speed, the intensity of sunlight, temperature, humidity, and chlorophyll content. As precision agriculture (PA) aims to generate excess yield by enhancing the resources, such as fertilizers, water, and pesticides, it allows farmers to have an exact measure of resources for healthy crops. The main lesson learned from this study is that IoT sensors and WSN technologies are mainly used for PA. Generating the prescription map requires not only the vegetation indices, but also the soil properties and meteorological comportment.

During the same year (2019), IoT-based systems in agriculture and farming were reviewed by presenting IoT software and hardware used in digital agriculture applications, such as farming system monitoring, as well as greenhouse and precision agriculture [18]. The authors of this paper describe the technical information existing in an IoT system. The main functions of wireless sensor nodes are sensing capability, data processing capability, data storage capacity, unlicensed radio-frequency band communication capability, low power consumption, small size, and low cost. The hardware part mainly contains sensors, data acquisition units (DAQ units), data processing units (DPUs), communication unit, and power supply unit. The software part mainly includes the operating system, drivers for sensors and actuators, and data networking stack.

Furthermore, discussions have been carried out on communication technologies, such as ZigBee, Bluetooth, and Wi-Fi by presenting their advantages and limitations. Finally, the main challenges faced by developing nations were discussed. We can quote the non-spreading of internet access available throughout the country, the non-literacy of farmers in these countries, and the threat of theft, damage, and vandalization of IoT devices. All of these challenges have slowed down the digital agriculture progress in these countries.

In 2020, a literature review was performed on machine learning techniques applied during data processing in wireless sensor network-based PA [19]. In particular, ML model features have been investigated in many papers for yield prediction, decision support for irrigation, and crop quality. Indeed, farms, including IoT, unmanned aerial vehicles (UAVs), and other technologies, induce millions of data production on the ground daily. These data should be analyzed by farmers with the help of artificial intelligence for making better decisions on forecasting and ensuring reliable management of sensors. In this work, the various ML algorithms were presented in two categories, such as supervised learning and unsupervised learning. The focus was on supervised learning as an unsupervised learning algorithm is used on exploratory applications where there is no specific set goal or the information the data consists of is not clear, whereas supervised learning exploits a known set of labelled data to train a model to forecast the target variable for out of sample data. Regression algorithms, such as decision trees, ensemble learning, Bayesian models, and artificial neural networks (ANNs) are the most developed algorithms. These algorithms are mainly used to predict temperature and humidity in a greenhouse environment, to predict the type of crop to be grown using sensor data from soil pH, temperature, and humidity, and to anticipate crop dysfunction proactively; the farmer is then notified with a possible remedy through smartphone, to analyze the sensor data for forecasting suitable temperature, humidity, and soil moisture of crops in the future, to forecast and detect pest/disease precisely using historical and real-time sensor data.

In 2021, the industrial revolution was compared to the agriculture revolution from traditional industry to modern industry and traditional agriculture to modern agriculture [20]. The roadmap relative to this comparison is presented in Figure 1, which indicates that industry and agriculture progress from mechanization to intelligence.

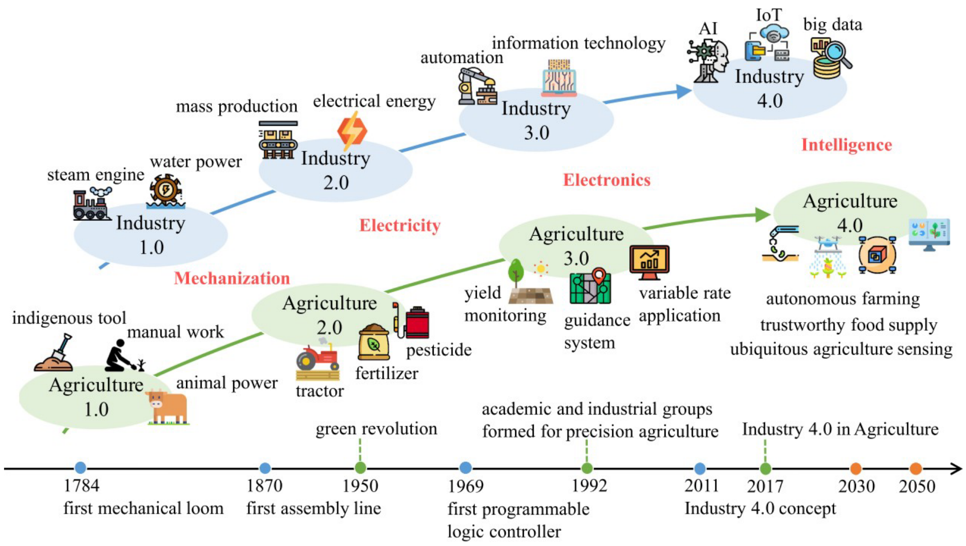

Figure 1. Roadmap of industrial and agriculture revolution [21,22].

Furthermore, agricultural progress is induced by industry progress. A literature review was performed on the key enabling technologies, such as IoT, robotics, big data, IA, and blockchain, which revolutionized digital agriculture. The focus was on smart farming applications and the research challenges relative to them. As many of them are used with the agricultural production chain, these authors discussed the relationship between the technologies' application to digital agriculture development.

As previously discussed, IoT collects and relays data-to-data analytics and deep learning for in-depth processing and analysis. These authors investigated the literature review on digital agriculture. They mainly focused their research on IoT, big data, and deep learning techniques [22]. Application fields of each technology are studied. The data collected by IoT systems help farmers in handling precision crop varieties, phenotypes, selection, crop performance, soil quality, pH level, irrigation, and fertilizer application quantity. Furthermore, the advantages of exploitation of deep learning algorithms are highlighted where deep learning is defined as an important branch of machine learning, which is trained on data sets and can detect patterns and anomalies in data generated by smart sensors. Moreover, big data technology cannot be solely used in digital agriculture. Its exploitation requires important data collection and assists farmers in being informed and making correct decisions about farming practices and management. Challenges affecting the adoption of these technologies are also studied, such as concerns about privacy and trust, profitability issues, lack of skills, cost challenges, lack of broadband infrastructure, and technical challenges. In 2022, an investigation has been carried out on digital technologies and services used to increase agriculture productivity and sustainability in Tanzania [23]. The digital technology varies from simple mobile and web-based applications, mostly for smallholders to complex autonomous, information, and cyber-physical systems used by large-scale farmers. The main results from the literature review showed that sustainable development requires digital precision technologies. Adopting and managing technologies by small-scale farmers differs from those of large-scale farmers. Moreover, the authors identified the digital solutions proposed in Tanzania for digital agriculture and the problems farmers face with different services that slow down the development of digital agriculture in this country.

In the same year, a systematic review was conducted on IoT and WSN for sustainable smallholder agriculture [24]. Indeed, smallholder farms can be defined as family-run, small farms that are often fragmented into disjoint plots, are nature-dependent and have limited operational budget, limited information access and technology support, and often display low production levels. The main gaps in the utilization of these technologies, in this case, have been highlighted, such as the problem of the literacy rate of farmers, the non-accessibility to information systems, and the requirement of human presence to perform all activities. Most smallholder farms usually practice farming based on natural biophysical conditions for crop growth, such as rain, and apply a mix of crop growing and livestock breeding. Nowadays, IoT and WSN technologies are used to increase productivity by assuming the efficient use of natural resources, such as water and sun, and monitoring real-time crops and breeding health. Four areas constitute the application field of IoT and WSN in smallholder agriculture: Precision agriculture, weather monitoring (WM), pest and animal infestation monitoring (PAIM), and livestock management (LM). This work investigated the rate application of these technologies in each field. It has been demonstrated that PA is the field which records 60% of publications, PAIM 16%, WM 1%, and LM 10%.

Furthermore, the different sensor types exploited in the works are studied and show that the four main environment properties are the most checked. There are soil moisture, humidity, air, and soil temperature. The additional parameters, such as light, motion, soil acidity, air pressure, wind speed and direction, CO_2 and solar radiation are also exploited. The data collected by sensors are processed and analyzed using simple computation, statistics, and machine learning. In this section, related work about a bibliometric study on digital agriculture and a survey on digital technologies are highlighted. While some papers present two technologies, others present three technologies. Moreover, we have not identified papers that present a survey of many technologies in conjunction with and related to many West African countries. The following section shows the methodology used in this paper.

2.3. Methodology

To contribute to digital inclusion in agriculture in West Africa, particularly in Benin, Burkina Faso, Cote d'Ivoire, Ghana, and Nigeria, we assessed the current state of innovation in each of these countries. We chose these countries since they are involved in the AGRIDI project (project for accelerating inclusive green growth through agri-based innovation in West Africa), an important project for growing innovation of digital agriculture in West Africa. For this purpose, we adopted a mixed methodological approach. The primary objective of this study is to assess the status of countries and knowledge of digital agriculture research in West Africa. This type of analysis can be carried out through a systematic analytical technique that identifies the most influential researchers, their affiliations, the keywords they choose and, most importantly, how academic work relates to each other. The bibliometric approach is appropriate for assessing the current status of a particular discipline using different indicators, such as highly cited publications, researchers, journals, academic institutions, and countries [25].

First, we reviewed the related work on review studies on digital agriculture. Second, through a quantitative approach based on bibliometric data analysis, we identified key research, authors, and their relationship, covering all publications related to a given topic or field. All scientific contributions to digital agriculture in West Africa were reviewed using this search string. The bibliometric search was performed on the Web of Science, and the bibliometric database was exported on 28 September 2022. The search string is: (Agriculture OR Agricultural OR "Food production" OR "Farming system" OR Farming) AND (Innovation OR Numeric OR Digital OR Smart OR Automatic OR "Artificial intelligence" OR "Internet of things" OR "Machine learning" OR "Automated learning" OR Blockchain OR "Big data" OR "Data science" OR "Wireless technologies" OR "Mobile network" OR "Sensor network") AND (Benin OR Nigeria OR "Ivory Coast" OR "Cote d'Ivoire" OR Ghana OR "Burkina Faso" OR "West Africa"). Using the search string presented above, 3249 publications were retrieved from the Web of Science, including articles, reviews, chapters, and proceedings. The records were exported in BibTeX and txt files, including authors, publication year, title, abstract, subject categories, source journal, and references. The data were analyzed using biblio-shiny, Bibliometric, and VOSviewer software. Third, we assessed the use cases and deployment of digital technologies in the countries through a systematic review approach based on a comparative analysis of technologies used in the target countries; papers have been selected based on the previous bibliometric study and other sources. At this stage, we relied on the content of the most cited articles and publications from the cases of the different organizations in the different countries, but also and above all, on papers presenting tangible cases of deployment in the target countries from sources, such as Scopus Science Direct, Google Scholar, IEEE, and MDPI. Published papers during the last 5 years were selected from the bibliometric study to perform a comparative analysis of technologies used in the target countries. In total, 468 scientific documents were retrieved. First, filtering was performed to exclude articles based on title, the origin of the study, and whether the innovation/technology is used in agriculture. A second filtering was performed by reading the abstracts, keywords, and conclusions. In total, after sorting, thirty papers dealing with practical cases of digital farming deployment in the five countries concerned allowed us to present the actual state of evolution of the countries with regard to digital farming. Based on this literature review, the primary lines of innovations and technologies were presented, as well as the context and level of advancement of West African countries.

3. Results and Discussion

3.1. Bibliometric Study

Bibliometric analysis is a computer-assisted scientific review methodology that allows for the identification of key research or authors and their relationship, covering all publications related to a given topic or field. In this section, we reported the results of the bibliometric study of the research on digital agriculture. We assessed the contributions of researchers, institutions, and target West African countries.

3.1.1. Annual Scientific Production

Figure 2 shows the number of publications on digital farming since 1975. It is easy to see that research interest in digital agriculture is not new. Since 1975, research work has focused on innovation in agriculture. However, since 2014, the research interest has increased considerably with publications. In 2021, more than 550 publications were indexed in the Web of Science.

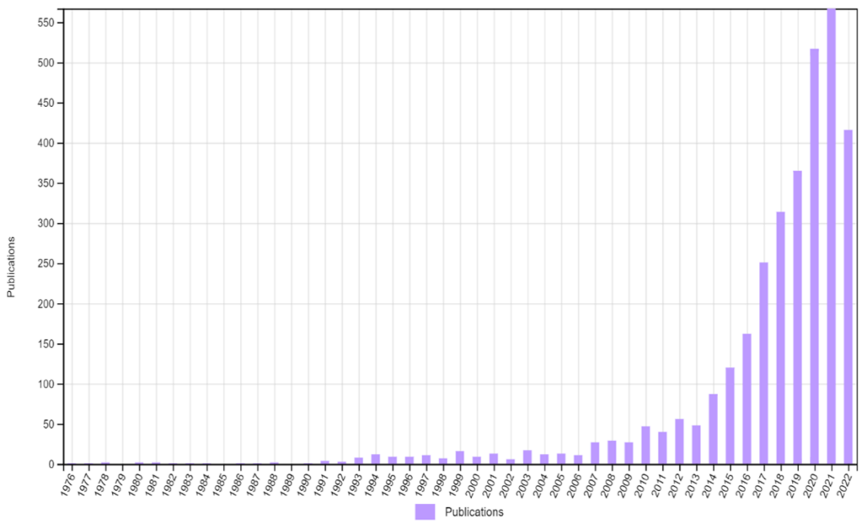

Figure 2. Histogram of publications per year.

3.1.2. Relevant Source

Figure 3 shows the top 20 most relevant sources of collected data. The African Journal of Science Technology Innovation ranks first with 83 documents published on the subject, then Discovery and Innovation with 82 documents, and Innovation and Technologies for Sustainable Agriculture with 62 documents.

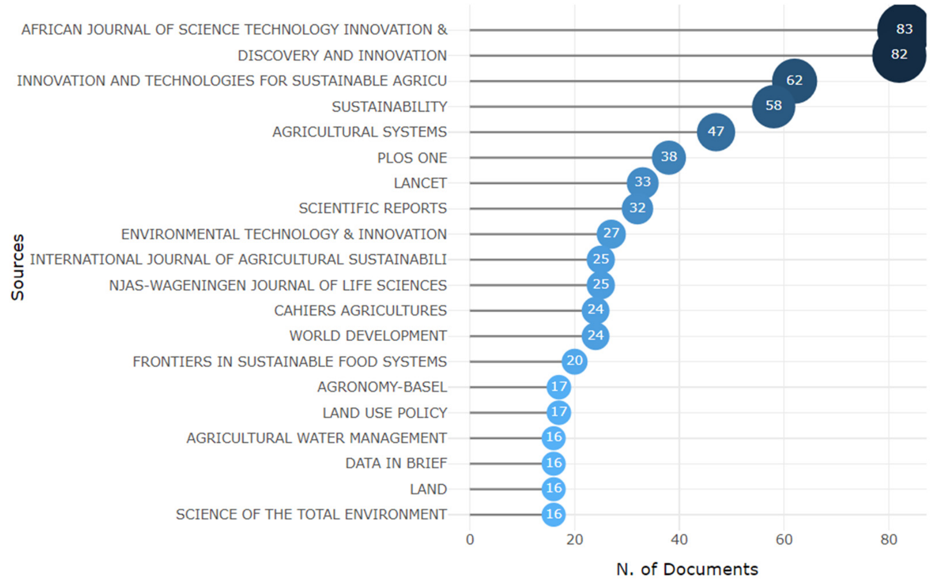

Figure 3. Top 20 most relevant sources.

3.1.3. Author Countries

Figure 4 presents the scientific contributions to innovation in digital agriculture according to the authors' countries of origin. In the five countries, the bulk of the publications in digital agriculture were obtained from Nigeria (the most populous of the five target countries), followed by Ghana. On the other hand, the English-speaking countries (Ghana and Nigeria) showed more contributions to advancing knowledge in digital agriculture compared to the francophone countries in the following order: Benin, Burkina, and Côte d'Ivoire. There is also strong collaboration between these countries and the rest of the world in these publications, including collaboration with other countries, such as England, USA, South Africa, German and China. Although this may call for increased scientific collaboration, it should be noted that only English-language publications were taken into account for this study.

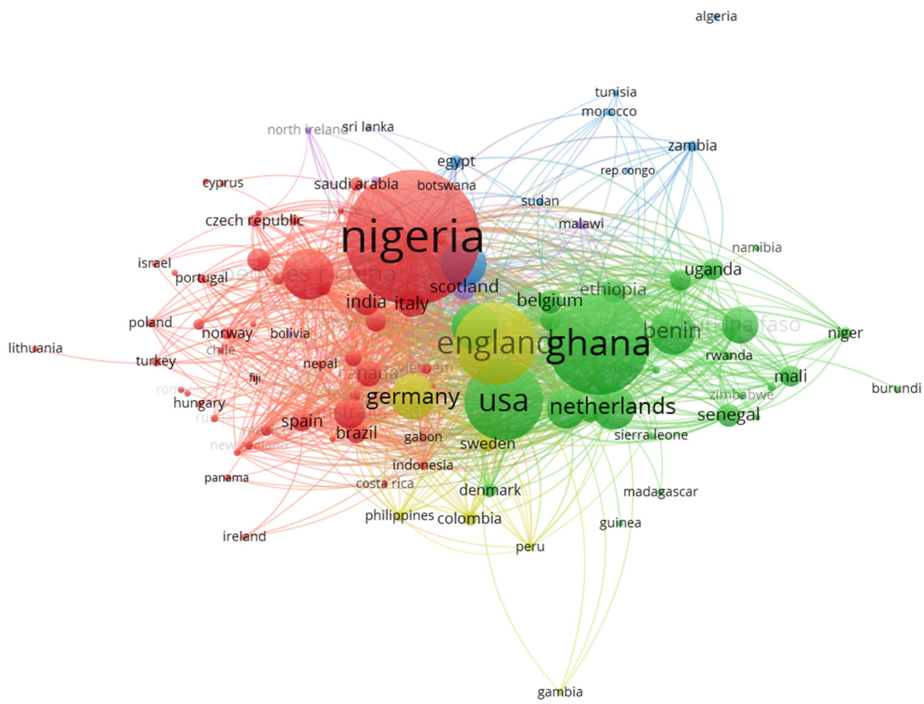

Figure 4. Map of author countries.

3.1.4. Author Organizations

Most of the publication sources were obtained from academia (Figure 5). The university of Ghana recorded the highest number of publications, followed by Nigerian universities (university of Nigeria, Opkara Agro university, university of Ibadan) and the university of Abomey-Calavi. Other sources include research institutions and international organizations.

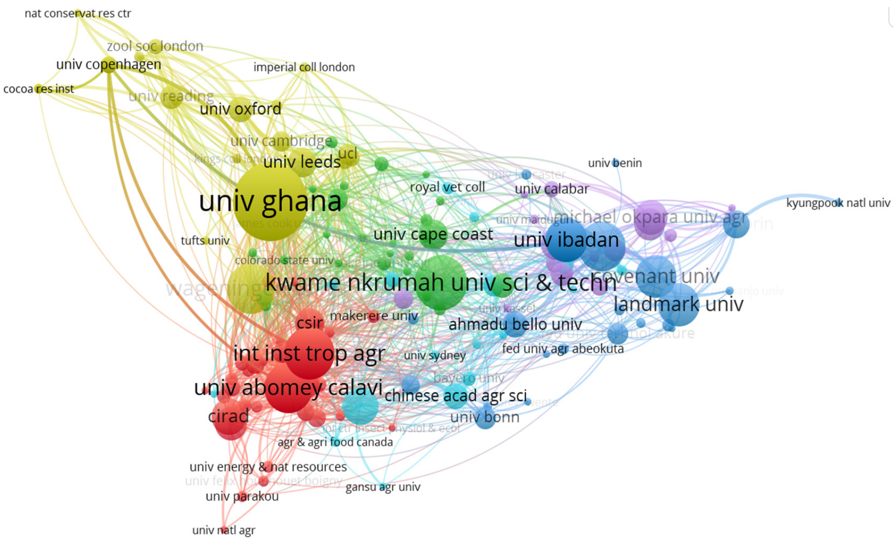

Figure 5. Map of author organizations.

3.1.5. Co-Occurrence Network

Figure 6 shows a graph of keywords used in the publications. Each node is associated with a keyword, and its size is proportional to the number of documents where it appears. Since the study focuses specifically on five countries, keywords, such as "Ghana", "Nigeria", and "Africa" were most recurrent. Climate change and machine learning adoption are the technical words with the highest weight. Machine learning, sensor networks, and artificial intelligence were the most explored digital agriculture technologies, and adoption was the significantly-discussed topic in the literature.

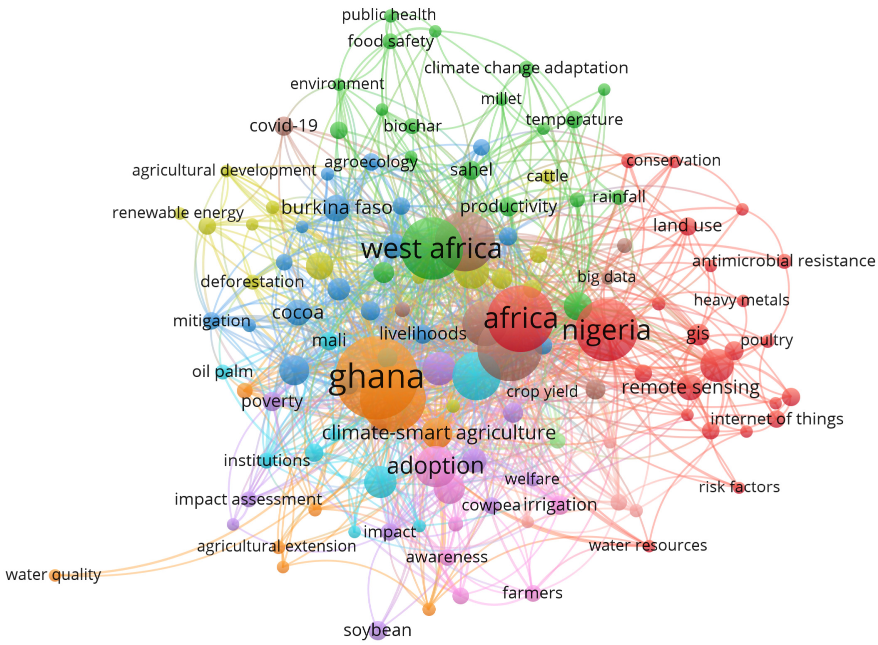

Figure 6. Co-occurrence network.

3.2. Digital Technologies Survey in the Five West African Countries

In this section, technologies applied in digital agriculture are reviewed for the target countries. This selection is obtained using papers recently published during the last 5 years and has shown that Nigeria has registered many publications on this topic (mainly in IoT and wireless sensor networks, blockchain, and AI). It is followed by Ghana, which has also been published. We can remember the following as a case study of the use of digital technologies in West Africa.

In Benin, AI is used for crop production to predict soil properties. AI is used for the production of bananas, dry beans, cassava, rice, maize, and seed cotton production in Burkina. It is used to predict weather data and chemical data. Moreover, IoT sensors are used for fish species production, bananas, and papayas production. They are used for meteorological parameters sensing, water pH, dissolved oxygen, temperature, and soil moisture sensing. In Cote d'Ivoire, AI monitors riverine water and increases sugarcane production. In addition, this technology is used to manage and analyze weather data, chemical data, the blockchain, AI, and big data. On the other hand, when Burkina Faso and Cote d'Ivoire published on IoT and AI, respectively, Cote d'Ivoire publications were rainfall data, temperature data, and sugarcane yields. In Ghana, AI manages soil water storage in landscapes and crop yield prediction. Big data is mainly used to collect data quality ownership and accessibility. Blockchain handles coca food and drug supply chains for transparency, traceability, enhancement, and mitigation of unethical activities. In Nigeria, AI is used for livestock and crop management, water and soil management, and breeding. Blockchain is used to create digital trust between agriculture stakeholders. IoT sensor networks are used for livestock monitoring, remote control sensing, precision irrigation, and triggering of automated irrigation systems. The smart village uses Lora for farm crops and water quality monitoring.

Table 1 presents a summary regarding the review performed on these technologies.

Table 1. Technologies survey in digital agriculture.

Papers	Digital Technology	Details	Applications
		Benin	
J. Aoga et al. [26]	AI, machine learning	random forest (RF) and extreme gradient boosting (XGB)	Crops, production (forecasting of soil properties)
		Burkina Faso	
Y. E. Gouly and A. Gusov [27]	digital platforms, artificial intelligence, and robotics	Agro-industrial platform	Crops yield production (cereal and rice production), livestock and fisheries production
E. Pignede et al. [28]	AI, machine learning, automatic learning	rainfall data, temperature data, and sugarcane yield analysis	Sugarcane yield forecasting using the random forest method
Gloria C. Okafor et al. [29]	Satellite images	Rain-fed agriculture prediction	cassava, yam, groundnut, maize, and sorghum crops production
G. Forkuor et al. [30]	IoT, WSN, and IA	Satellite spectral data, terrain and climatic variables analyzed based on multiple linear regression (MLR), random forest regression (RFR), support vector machines for regression (SVM), and stochastic gradient boosting (SGB)	prediction of soil properties
T. W. Zoug- more et al. [31]	IoT	Sensor measure parameters, such as pH, dissolved oxygen, water temperature, soil moisture, and meteorological parameters (wind speed, air humidity, rainfall, sunshine)	soil moisture properties for papaya and banana crop production

Table 1. *Cont.*

Papers	Digital Technology	Details	Applications
		Cote d'Ivoire	
M-P. Soro et al. [32]	AI, machine learning	Artificial neural network	Riverine water monitoring
E. Pignede et al. [28]	AI, machine learning, automatic learning	Rainfall data, temperature data, and sugarcane yield analysis	Sugarcane yield forecasting using the random forest method
		Ghana	
S. Musah et al. [33]	Blockchain	Transparency and traceability enhancement, unethical activities mitigation	Cocoa bean food supply chains
S. Vyas et al. [34]	AI and blockchain	Food supply chains and drug supply chains management, quality maintenance, and intelligent prediction	Drug supply chain
D. Wally et al. [35]	Big data and ICT	Satellites and remote sensors, mobile phone and remote sensors, accounting software, and GPS	farmers income increasing, data quality, ownership, and accessibility
N. K. A. Appiah-Badu et al. [36]	AI, machine learning	Random forest and extreme gradient boosting method for rainfall prediction, temperature (minimum and maximum), relative humidity, sunshine hours, and wind speed data prediction	ecological zone
K. A. Nketia [37]	AI, machine learning	Random forest, extreme gradient boosting algorithms	soil water storage in landscape
L. S. Cedric et al. [38]	AI and big data	Crops yield prediction weather data and chemical data	predict bananas, dry beans, cassava, rice, maize, and seed cotton
C. Nyamekye et al. [39]	AI, machine learning	Evaluation of the transitions among the major land use/land cover categories in machine learning algorithms (random forest) and intensity analysis	Environment
		Nigeria	
U. S. Abdul- lahi et al. [40]	IoT-LoRaWAN	Precision agriculture that uses analytic measurements to optimize farming decisions	Livestock farming: IoT helps farmers in making lists, preparing reports, sorting cows by category, and tracking each animal's overall lifetime
U. C. Njoku et al. [41]	Wireless sensor networks (WSNs)- LoRaWAN	Remote monitoring system of the environmental weather and soil conditions of the farmland to trigger irrigation automatically	field monitoring for rural farmers and automatic irrigation system
L. A. Ajao et al. [2]	IoT: WSN-Wi-Fi	Agro-climatic field parameters sensing using soil pH meter, soil moisture, and environmental temperature and humidity sensors. Energy consumption system managing using algorithmic state machine technique	Regular farm crops monitoring using the low energy consumption system
H. Borg- wardt [42]	Digital platforms, GPS tracking solution with LoRaWAN	Survey on smart farming and adoption	digital applications for market access and crowd farming, digital applications adoption
O. Elijah et al. [43]	IoT and data analysis	The application of IoT technologies and data analysis in agriculture: Sensing monitoring, use of RFID, etc.	Plant farms, animal farms, automated machinery, aquaponics
A. M. Manoha-ran, and V. Rathinasabapthy [44]	IoT-LoRaWAN	The LoRa mote along with sensors are placed in water tanks at villages and within corporation limits	smart village: Water quality monitoring and distribution, chemical leakage detection in rivers

Table 1. *Cont.*

Papers	Digital Technology	Details	Applications
N. Bore et al. [45]	blockchain	Agribusiness digital wallet (ADW) system development, which leverages blockchain to formalize the interactions and enable seamless data flow in small-scale farming ecosystem	Small-scale farming formalization digital trust establishment among the agriculture stakeholders
E. Omo Ojugo [46]	Big data	Big data analytics adoption for farming practices enhancement	Yield improvement
M. A. Umar et al. [47]	AI, machine learning, and deep learning	Models, such as ANN, SVM, EL/RF, ANN-XY, CNN, MLR, hybrid ANN, LSTM, LR/Bagging tree, FFNN, DT, BP, GWR, and XGBoost are used	Crop management, livestock management, water, and soil management
R. W. Bello et al. [48]	AI, machine learning and deep learning	Enhanced mask region-based convolutional neural networks (mask RCNN)	breeding improvement
Nwabueze, C. A. et al. [49]	WSN and GSM communication technology	Design of smart irrigation system to improve agricultural yield	Monitoring and control of various environmental factors, such as soil moisture and temperature
Ajibola O. [50]	WSN applications	Review on WSN: Measure of parameters, such as pH level, electrical conductivity, oxidation-reduction Potential (ORP), turbidity	Monitoring of the water quality distributed in the country
Asogwa, T. C. et al. [51]		Sensor nodes deployed in farm field to measure air temperature, relative humidity, and soil moisture. They are also used to keep livestock healthier with a minimum use of resources	Use of sensor nodes to monitor micro-climates in a potato, millet, or cassava field. Determination of the pH level and temperature inside the cow's rumen
Bolaji A. A. et al. [52]		Electronic-cattle health monitoring using WSN	Cattle parameters monitoring, such as farming environment, cattle movement, cattle health, reproduction management, lactation and rumination monitoring
Abdulkadir S. B. et al. [53]		Design of forest fire monitoring system using sensors. Arduino microcontroller is used as the brain of the research to regulate input from the AMG8833 sensor and GPS Ubox 6 M	hotspots detection from 19.25 to 122.5 °C by sensor nodes, which present the capcacity to detect fire in the distance range of 2.5 to 10 m
Trisha D. B. et al. [54]		Remote sensing techniques of draft monitoring, traditional drought, and surface water body monitoring	Techniques tracking droughts using remote sensing, including its relevance in monitoring climate variability and hydrological drought impacts on surface water resource

From the results of the survey on digital agriculture, one can note that while many papers discussed one of the emerging technologies for digital agriculture in one or two countries [28], other papers discussed two technologies for digital agriculture in one country [44]. No paper has presented a survey on all emerging technologies in digital agriculture. Furthermore, no bibliometric study has been performed on digital agriculture in the five countries. This work constitutes the basis for the researcher that would like to perform research on a specific technology used in digital agriculture.

3.3. Lessons Learned

The analysis of the status of digital agriculture across the five countries provides insights into each country's efforts in digital agriculture. There are many ongoing initiatives in these countries to develop the sector. Most of the systematic analyses are useful for only one analysis: Bibliometric. However, in our research, we have not only carried out bibliometric analysis, but also surveyed practical cases of deployment in the countries considered. As in [4], this study highlighted the importance of research in IoT and machine learning. However, in contrast to the developing countries presented in [54], technologies, such as blockchain are not yet well developed in Africa. However, in line with the development in [7], technology adoption is a topic of interest in the five countries considered.

The in-depth studies carried out after the literature review showed that by using IoT-based solutions in agricultural production, many problems specific to the realities of West Africa can be solved, such as livestock theft and water pollution. IoT, sensor networks, and artificial intelligence are exploited to develop intelligent systems for crop and livestock farm monitoring and to improve animal and plant health care. The explosion of data science and big data offers impressive tools and models for predictive analysis. The wealth of data from agriculture and its analysis can be harnessed to improve farming practices in order to increase crop yields and reduce input costs. Machine learning implements very high-accuracy models to make predictions on several aspects and prevent environmental hazards and promote precision agriculture. The application of blockchain technology makes the food supply chain more efficient by tracking all transactions. These innovations have been proven and demonstrated by practical cases specific to the realities of West Africa in the literature. However, it must be noted that in West African countries, despite the potential of technologies and their ability to boost the field of agriculture, even though in real situations, the technologies have had to prove themselves, agriculture remains more traditional than digital. Practical agricultural solutions are not popularized and deployed in large-scale situations.

4. Conclusions

This study was conducted to assess the level of adoption of digital technologies in five West African countries, namely, Benin, Ghana, Burkina-Faso, Nigeria, and Côte d'Ivoire, within the framework of the AGRIDI project. It consisted of a bibliometric analysis and a systematic review of digital technologies in these countries. Then, a description of the technologies adopted in these countries was presented. The study revealed that digital technologies used in agriculture include blockchain, the IoT, big data, machine learning/deep learning methods, etc. Nigeria is the most advanced of the five countries in adopting digital agriculture technologies, followed by Ghana and Cote d'Ivoire. Benin and Burkina Faso are ranked as countries with minor use of digital technologies. While AI and big data are the most used technologies in Côte d'Ivoire and Ghana, IoT and WSN are the most used in Nigeria. Applications of agriculture developed in the literature are related to crops production (bananas, sugarcane, dry beans, cassava, rice, maize, and seed cotton) monitoring, riverine water monitoring, livestock's farm monitoring, fish production monitoring, forest fire monitoring, food supply chains and drug supply chains management, and tracking droughts. This study highlights not only the level of progress in digital agriculture in five countries, but also the key organizations working in the field and the terms frequently used. This work constitutes a reference for researchers interested in working in the sector and a tool to help in seeking an improvement in digital agriculture. Further work should be carried out in West African countries on the digitalization of agriculture. In the perspective of this work, we will extend the study to other African countries and not only study the technology, but also the strategies and policies that are developed to promote the development of agriculture in Africa.

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