Colombian agriculture: approaching agriculture 4.0

Agricultura colombiana: aproximación a la agricultura 4.0

Agricultura colombiana: abordagem da agricultura 4.0

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Abstract

Introduction: This article is the product of the research "Agriculture 4.0 in Colombia" developed at the Universidad Distrital Francisco José de Caldas over a three-year observation window: 2019, 2020 and part of 2021. Here, we present some of the most relevant aspects related to the technological development of Colombian agriculture and of projects that have been carried out in the country in the field of precision agriculture. It also addresses the context of the progress of Agriculture 4.0 at the national level and presents possible IoT integration tools and architectures applicable in this field. Finally, the benefits and implications of the development of Agriculture 4.0 in the country are highlighted, concluding that its consolidation is necessary to strengthen national agricultural development.

Methodology: A review of information on precision agriculture and Agriculture 4.0 in Colombia was carried out, covering scientific articles from databases such as IEEE Explore, Scopus and Elsevier, and official documents from governmental websites.

Results: The development of Agriculture 4.0 in Colombia has not yet been fully explored, however, research and pilot projects have been carried out on Agriculture 4.0 in the national territory.

Conclusions: To strengthen the deployment of Agriculture 4.0 in Colombia, it is necessary to invest in technology, provide education and training, promote research, and adopt modern technological practices in agricultural activities.

Originality: The context of the development of Agriculture 4.0 in Colombia in terms of projects and research is presented, as well as some IoT integration architectures and tools applicable in Colombian agriculture.

Limitations: The information available regarding Agriculture 4.0 in Colombia is scarce.

Keywords: Precision agriculture, Agriculture 4.0, architectures, automation, crop.

Resumen

Introducción: Este artículo es producto de la investigación "Agricultura 4.0 en Colombia", desarrollada en la Universidad Distrital Francisco José de Caldas en una ventana de observación de tres años: 2019, 2020 y parte de 2021. Aquí se presentan algunos de los aspectos más relevantes relacionados con el desarrollo tecnológico de la agricultura colombiana y de proyectos que se han realizado en el país en materia de agricultura de precisión. Así mismo, se aborda el contexto del avance de la agricultura 4.0 a nivel nacional y se presentan posibles herramientas y arquitecturas de integración IoT aplicables en este ámbito. Por último, se resaltan los beneficios e implicaciones que conlleva el desarrollo de la agricultura 4.0 en el país, concluyendo que su consolidación es necesaria para fortalecer el desarrollo de la agricultura nacional.

Metodología: Se realizó una revisión de información referente a agricultura de precisión y agricultura 4.0 en Colombia, en artículos científicos de bases como IEEE Explore, Scopus y Elsevier, y documentos oficiales de páginas gubernamentales.

Resultados: El desarrollo de la Agricultura 4.0 en Colombia aún no se ha presentado en su totalidad, sin embargo, se han realizado investigaciones y proyectos piloto en materia de Agricultura 4.0 en el territorio nacional.

Conclusiones: Para fortalecer el despliegue de la Agricultura 4.0 en Colombia es necesario realizar inversiones en tecnología, brindar educación y capacitaciones, fomentar investigaciones, y adoptar prácticas tecnológicas modernas en las actividades agrícolas.

Originalidad: Se presenta el contexto del desarrollo de la Agricultura 4.0 en Colombia en materia de proyectos e investigaciones, así como algunas arquitecturas de integración IoT y herramientas aplicables en la agricultura colombiana.

Limitaciones: La información disponible en cuanto a Agricultura 4.0 en Colombia es escasa.

Palabras clave: Agricultura de precisión, agricultura 4.0, arquitecturas, automatización, cultivo.

Resumo

Introdução: Este artigo é produto da pesquisa "Agricultura 4.0 na Colômbia", desenvolvida na Universidade Distrital Francisco José de Caldas em uma janela de observação de três anos: 2019, 2020 e parte de 2021. Aqui estão alguns dos mais relacionados o desenvolvimento tecnológico da agricultura colombiana e os projetos realizados no país no campo da agricultura de precisão. Da mesma forma, aborda-se o contexto do avanço da agricultura 4.0 em nível nacional e são apresentadas possíveis ferramentas e arquiteturas de integração IoT aplicáveis neste campo. Por fim, destacam-se os benefícios e implicações do desenvolvimento da agricultura 4.0 no país, concluindo que sua consolidação é necessária para fortalecer o desenvolvimento da agricultura nacional.

Metodologia: Foi realizada uma revisão de informações sobre agricultura de precisão e agricultura 4.0 na Colômbia, em artigos científicos de bases como IEEE Explore, Scopus e Elsevier, e documentos oficiais de páginas governamentais.

Resultados: O desenvolvimento da Agricultura 4.0 na Colômbia ainda não foi apresentado em sua totalidade, no entanto, pesquisas e projetos pilotos foram realizados sobre a Agricultura 4.0 no território nacional.

Conclusões: Para fortalecer a implantação da Agricultura 4.0 na Colômbia, é necessário investir em tecnologia, proporcionar educação e capacitação, promover a pesquisa e adotar práticas tecnológicas modernas nas atividades agrícolas.

Originalidade: O contexto do desenvolvimento da Agricultura 4.0 na Colômbia é apresentado em termos de projetos e pesquisas, bem como algumas arquiteturas e ferramentas de integração IoT aplicáveis à agricultura colombiana.

Limitações: A informação disponível sobre Agricultura 4.0 na Colômbia é escassa.

Palavras-chave: Agricultura de precisão, agricultura 4.0, arquiteturas, automação, cultivo.

1. INTRODUCTION

The incursion of smart technologies in agriculture has allowed for the modernization of various activities and processes that have transformed the agricultural production chain in several countries, thus achieving the optimization of field works thanks to the use of tools related to information technology, Big Data, IoT and automation, among others. From this, in the last decade, the development of Agriculture 4.0 has taken place, which encompasses concepts ranging from precision agriculture, monitoring, decision-making; as well as those related to Industry 4.0, IoT, machine learning, sustainability and automation, among others. This is evidenced in the diagram generated by the VOSviewer software based on the bibliographic data obtained in Scopus from the search for the topic 'Agriculture 4.0' and performing a co-occurrence analysis, showing the most common topics related to this search in the last ten years (Figure 1).

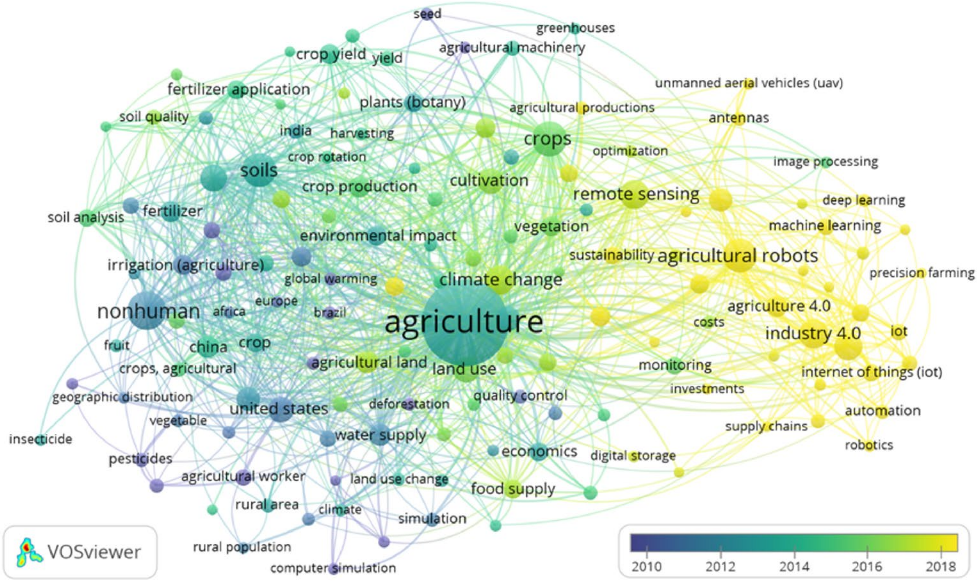

Figure 1. Co-occurrence networks of concepts related to Agriculture 4.0 over the last ten years.

Source: Own work, made with VOSviewer software.

In Colombia, agriculture is one of the activities that has contributed significantly to the country's development, with the agricultural sector being one of the main contributors to the Colombian economy and sustainable development. Given the geographical and climatic variety, Colombian agriculture stands out for being very diverse and also have great potential, but due to factors related to productivity, innovation, quality standards, among others, the country's agricultural development has lagged and the need to establish policies in line with the technological advances of agriculture worldwide is increasing [1].

An Agricultural Production Unit - APU is defined as an agricultural production organization unit that produces agricultural, forestry, livestock, and aquaculture goods. It also has a single natural or legal producer and uses some means of production such as machinery, workforce, buildings, or equipment on its land [2]. Currently, of the total land use in the country, 9.2% corresponds to agricultural use (Figure 2), with approximately 2,085,423 APUs, of which 6.6% have some type of ICT asset (mobile devices, computers, GPS, tablets, among others) and only 1.7% have Internet access [3].

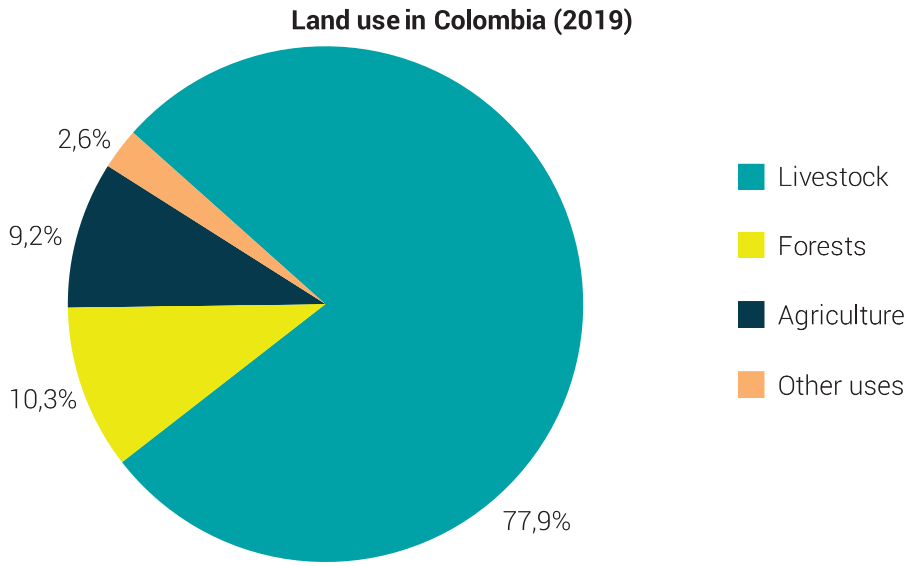

Figure 2. Land use in Colombia.
Source: Adapted from [3].

Regarding the science, technology, and innovation activities carried out in the APUs, 2.9% were developed in agricultural activity processes in aspects such as production processes, products, marketing, or administration, largely to improve the profitability of their activities. Regarding the use of agricultural machinery for the development of their activities, only 18.5% of the APUs make use of it, in contrast with 78.2% that do not use machinery (Figure 3) [3].

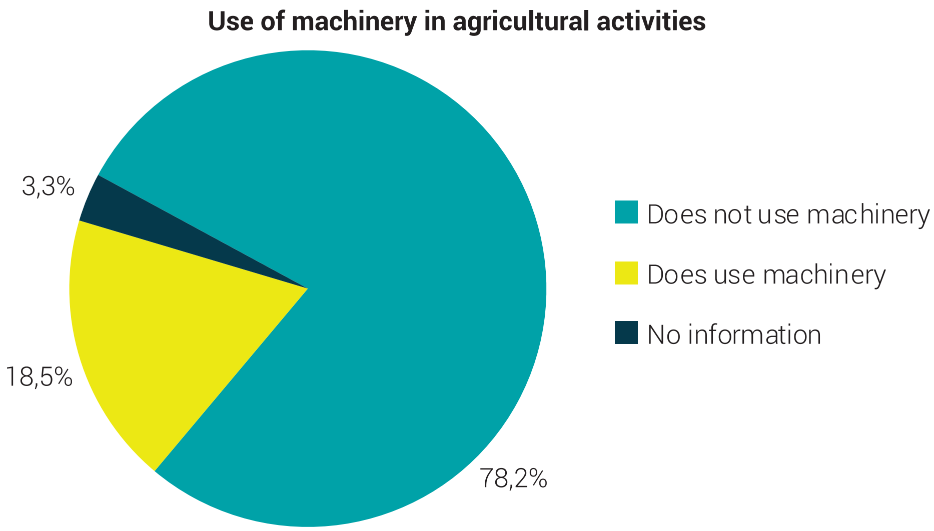

Figure 3. Percentage of APUs using machinery in agricultural activities.
Source: Adapted from [3].

Traditional Colombian agriculture is characterized by the use of ancient techniques that have been applied by several generations of Colombian farmers and are still in use today, either because they are associated with deep-rooted cultural knowledge or because the technological gap is an obstacle to the adaptation and application of new technologies in agriculture. The development and implementation of technologies that contribute to improving the activities carried out in agriculture and increase the productivity of the sector have been presented late in Colombia if we make the comparison with worldwide projects and advances made in precision agriculture and Agriculture 4.0; however, in the last decade, some projects related to precision agriculture have been implemented that involve the application of ICT and IoT and that can be considered as a basis for the further development of Agriculture 4.0 in the country. Based on the above, this article presents a review of the most relevant aspects related to the technological development of Colombian agriculture and projects that have been carried out in the country in the field of precision agriculture. It also addresses the context of the progress of Agriculture 4.0 at the national level and presents possible IoT integration tools and architectures applicable in this field. Finally, the benefits and implications of the development of Agriculture 4.0 in the country are highlighted, emphasising through this work the importance and necessity of the consolidation of Agriculture 4.0 to strengthen national agricultural development.

2. PRECISION AGRICULTURE IN COLOMBIA

Precision agriculture "is a concept of agricultural management that uses digital techniques to monitor and optimize agricultural production processes" [4, p. 4]. Precision agriculture aims to optimize the management of agricultural production by taking into account soil and crop variability, by using technologies that allow agricultural activities to be adjusted according to the specific requirements of the soil and the plant. The beginnings of precision agriculture date back to the late 1980s in Europe and the United States, while in Latin America it began in the late 1990s and early 2000s, with Argentina and Brazil being pioneers in the implementation of precision agriculture practices. In Colombia, given that traditional agricultural practices continue to be used in most agricultural work, the boom in precision agriculture has been occurring in the last decade with the implementation of technologies and the development of projects in the cultivation of relevant agricultural products in the country, such as coffee, sugarcane, and oil palm.

The traditional agricultural practices prevailing in the country have brought about adverse effects reflected in low crop productivity, inefficient use of resources, and generalized management of crops without taking into account their specificities, which have a negative impact on both the farmers' economy –since profitability is determined by the potential of their crops– and on the environment –since the ecological impact caused by the inadequate management of inputs and resources contributes to land degradation–. Based on this, precision agriculture has made inroads in Colombian agriculture as a solution to the counterproductive effects of traditional agricultural practices, generating benefits such as increased crop productivity due to the use of the production potential of the land, reduced use of fertilizers, and waste of resources since their use is based on the specific requirements of the crop and/or soil, reduced negative impacts due to land degradation and reduced production costs.

The development and implementation of precision agriculture technologies in the country have been achieved as a result of research work by universities, institutions, research centers for Colombian agricultural products, and public and private companies, such as the National University of Colombia, the University of the Llanos, the University of Nariño, Cenicaña, Cenicafé, Cenipalma, SENA, IGAC and Ingenio Río Paila-Castilla, among others. In most cases, the precision agriculture applications and projects developed a focus on aspects such as soil variability analysis, use of geographic information, use of sensors, and drones [5].

Regarding unmanned aerial vehicles or drones, their boom in the country began in 2015, being used in remote sensing processes as part of precision agriculture technologies focused on crop management. The images obtained by drones, also known as UAV's (Unmanned Aerial Vehicles), are mostly used in the activities of monitoring, tracking, and identification of diseases in crops of a smaller extension of land; while for crops of large extensions the use of satellite images is employed [6].

Concerning the application of precision agriculture technologies and the layout of plantations along with the management of pests and crop diseases, research conducted by the Center for Oil Palm Research (Cenipalma) in 2011 showed that by performing the automatic layout of plantations with the use of AMS technology (Agricultural Management Solutions of the brand John Deere) a significant improvement in the performance of this activity can be obtained if compared to the performance obtained by doing the layout manually; additionally, the effectiveness of the use of geographic information technologies in activities related to agronomic management activities was demonstrated [7]. With the support of Corpoica (Colombian Agricultural Research Corporation), research was conducted in 2015 related to the analysis of multispectral images using drones [8], from which it was concluded that the use of this precision agriculture technology is very useful when carrying out activities related to the monitoring and diagnosis of the development conditions of a crop;

as drones facilitate the use of multispectral cameras from which images of varied tonalities can be obtained to identify problems in specific areas of the crop.

Regarding the application of precision agriculture in the fertilization process, in 2018 an investigation was carried out on banana crops using satellite images, drones for the collection of aerial images and sensors to perform measurements of soil variables, to obtain the characterization of the soil and subsequently identify and determine the agronomic management units (AMU); these being understood as "a spatial unit of cultivation within which there is relative homogeneity in the variables that affect productivity" [9, pp. 42-51]. With this, it was possible to establish with greater precision the number of inputs required for each AMU according to its specific characteristics, thus reaching the conclusion that the fertilization plan developed for each AMU, based on the information obtained through the application of precision agriculture technologies, decreases production costs as the use of fertilizers is lower compared to traditional management [10].

3. AGRICULTURE 4.0 IN COLOMBIA

Agriculture 4.0 began in the early 2010s with the development and evolution of technologies such as sensors, ICT systems, microprocessors, IoT, and Big Data [11]. It "consists of the integration of agricultural processes with information technologies, using algorithms, massive amounts of data acquired in the field by sensors, to increase crop productivity and improve the management of rural properties" [12, p. 13]. In this way, the incursion of smart technologies in agriculture gave way to the modernization of various activities and processes that have transformed the agricultural production chain in several countries, thus achieving the optimization of fieldwork thanks to the use of tools related to information technologies, Big Data and data science, and automation [12].

As support for decision making related to crop management, Agriculture 4.0 uses tools such as sensors to obtain data from the field, IoT to send the data obtained to the network, cloud computing technologies to access data and information on the Internet, Big Data for the analysis of the data and information collected, and in some cases connectivity between mobile devices and machine-to-machine (M2M) communication [13]. According to the World Government Summit [14], some of the technologies employed in Agriculture 4.0 that are contributing to the transformation of agriculture focus on the use of new techniques for food production such as hydroponic agriculture, and the incorporation of technologies such as automation, IoT, drones in planting activities, irrigation, crop analysis, and monitoring, and Blockchain to optimize traceability and security in food supply chains.

Due to the technological and digital gap and the lack of policies in line with current technological advances, the development of Agriculture 4.0 has not been fully adopted in the country; however, in recent years, some actions, projects, and research have been carried out that can be considered as the foundations for a future incursion of Agriculture 4.0 in Colombia. One of these actions was the creation, in 2017, of the "Strategic Plan for Science, Technology, and Innovation of the Colombian Agricultural Sector 2017-2027 (PECTIA for its Spanish acronym)" and the National Agricultural Innovation System (SNIA for its Spanish acronym). These strategies are designed to improve productivity, sustainability and strengthen the Colombian agricultural sector through research, innovation, knowledge management and technological development activities [15]. Another foundational action for the development of Agriculture 4.0 in the country took place in recent years with the implementation of the Smart Agro 4.0; a project of FAO in collaboration with the company Telefónica, which also had coverage in Peru and El Salvador, and whose implementation began in 2018 and ended in 2020. This pilot project aimed to apply innovation and digitalization technologies to promote sustainable agricultural practices, for which it made use of an integrated system that allowed control activities, monitoring, and prediction of agronomic variables, using water sensors and a mathematical model for obtaining and processing crop data. In the case of Colombia, the project was carried out in potato and coffee crops and, by 2019, the results obtained showed that potato production had doubled, its quality had improved and there was a decrease of approximately 44% in unit production costs; all achieved thanks to the implementation of technological improvements in the crop irrigation systems [16].

Regarding research developed in the country and that have applied Agriculture 4.0 tools, there is the implementation of a wireless sensor network for the irrigation control system of a strawberry crop in the highlands of Pasto [17], from which information is obtained on soil moisture in various areas of the crop and subsequently determines the specific area and the required irrigation time of the same. This is executed through a closed-loop control system that uses soil moisture, which is measured by the sensors as an output variable and then feeds it back to the controller that generates the action to be executed by the respective actuators. The application of this system, in contrast to traditional irrigation, improved water use in the irrigation activity and, in turn, a significant improvement in fruit quality was obtained. Also, a study was conducted in which drones were used for monitoring and diagnostic activities of a potato crop in Cundinamarca [8] whose results were reflected in the reduction of work and time spent in the execution of these agricultural activities; drones, coupled with multispectral cameras, obtain high-resolution images with which it is easier to identify the problems that crops present, helping to better determine the necessary measures to intervene in the specific affected area [18].

4. IoT INTEGRATION ARCHITECTURES AND TOOLS APPLICABLE TO COLOMBIAN AGRICULTURE

Globally, several types of research have been carried out to develop complements and technological solutions that improve the performance and productivity of agricultural activities, taking into account the aspects covered by Agriculture 4.0 and its implementation through IoT technologies which, when applied to agriculture, comprise some main aspects which are: Physical structure or hardware components, data acquisition, and their respective processing and analysis [19]. In this way, proposed architectures for precision agriculture have been generated, mostly focused on monitoring crop variables.

In Colombia, for example, researchers from Armenia and Popayán conducted an IoT architecture proposal for the analysis of climatic variables of a crop based on the Lambda architecture to establish the layers of the structure of the proposed architecture [20], which consist of: a Capture layer, made up of hardware components such as sensors and data acquisition modules; a storage layer, to store the data collected through databases and storage servers; a processing layer, in which data analysis is carried out using interpretation tools; and a query layer, which provides the visualization of the information to the end-user to know the behavior of the climatic variables of the crop, as well as receive recommendations to make decisions according to the requirements presented by the crop (Figure 4). This proposed architecture highlights the use of low-cost sensors and the Arduino YUN board for their ease of use as tools to capture the climatic variables of the crop, as well as the use of the free software Weka for data mining, with which the information was presented to the user in the graphical interface of the query layer.

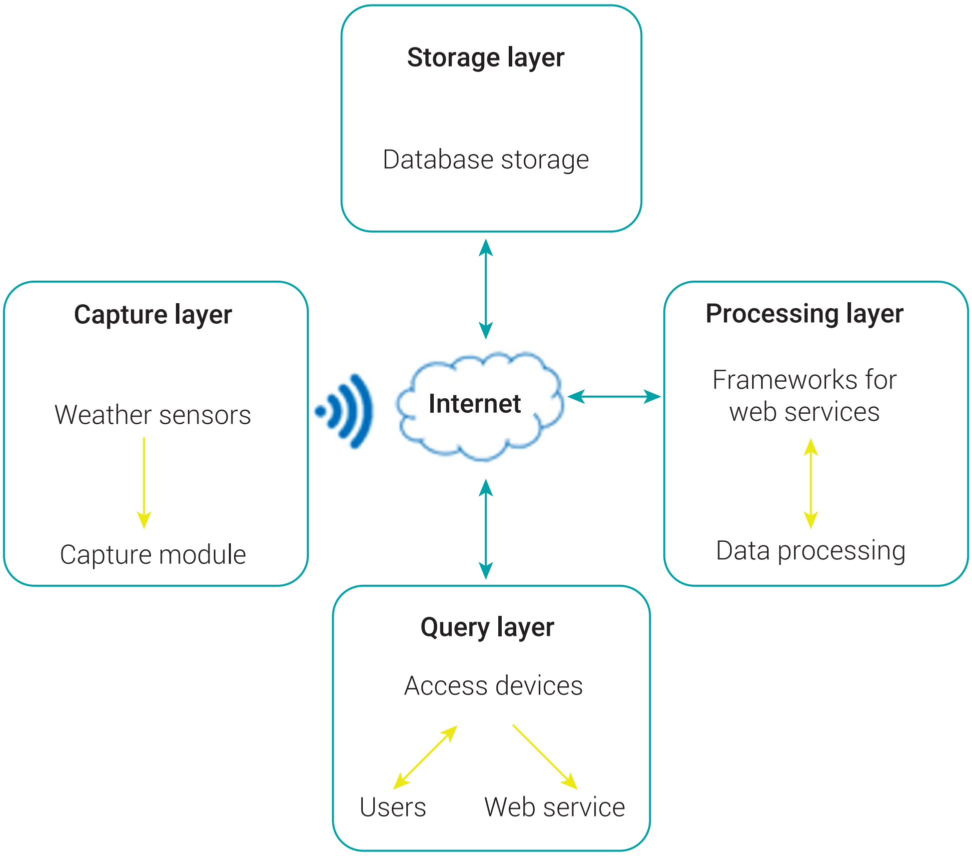

Figure 4. Proposed architecture.
Source: Taken from [20].

Similar to this, researchers in Mexico developed a platform to perform monitoring activities in both greenhouses and crop fields called SGreenH-IoT, which employs cloud services for storage and analysis of the information obtained, and also generates alerts on crop status that allow timely decisions to be made to improve crop production [21]. The architecture of this platform is composed of four layers (Figure 5): Collection, which includes sensors and actuators as hardware components of the platform; communication, where through the use of the ZigBee protocol the collected data are sent to a cloud storage server; management, where a cloud server analysis of such data is performed; and consultation, which presents the information through web pages and with an interface that allows the end-user to activate the systems, either manually, automatically or timed according to the decisions made based on the crop status information.

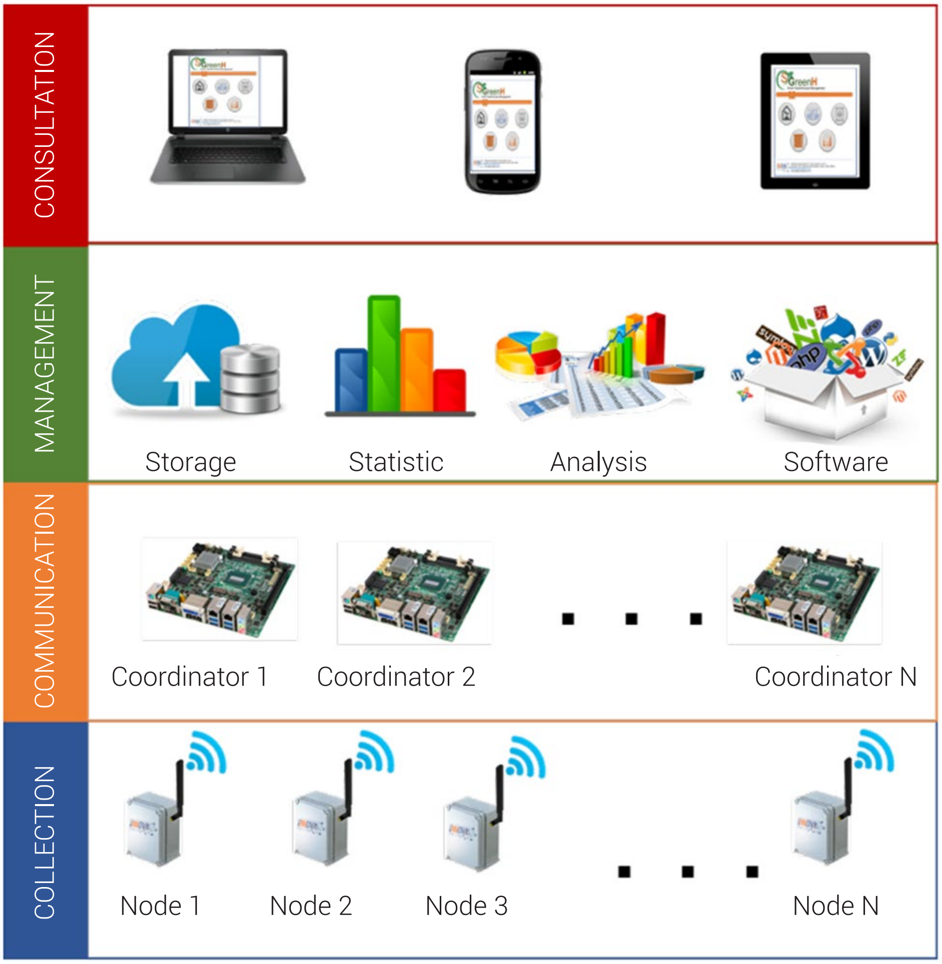

Figure 5. SGreenH-IoT architecture.
Source: Taken from [21].

Also related to the monitoring of crop variables, an architecture for a soil pH measurement system consisting of 3 modules was presented [22]: The first module comprises the collection and processing of data acquired by sensors in the field; the second module uses databases to centralize the information, and the third module presents the information to the end-user (Figure 6). Thus, from the deployment of this system, it is possible to develop tools that complement the information related to the spatial variability of the terrain, such as the elaboration of soil maps.

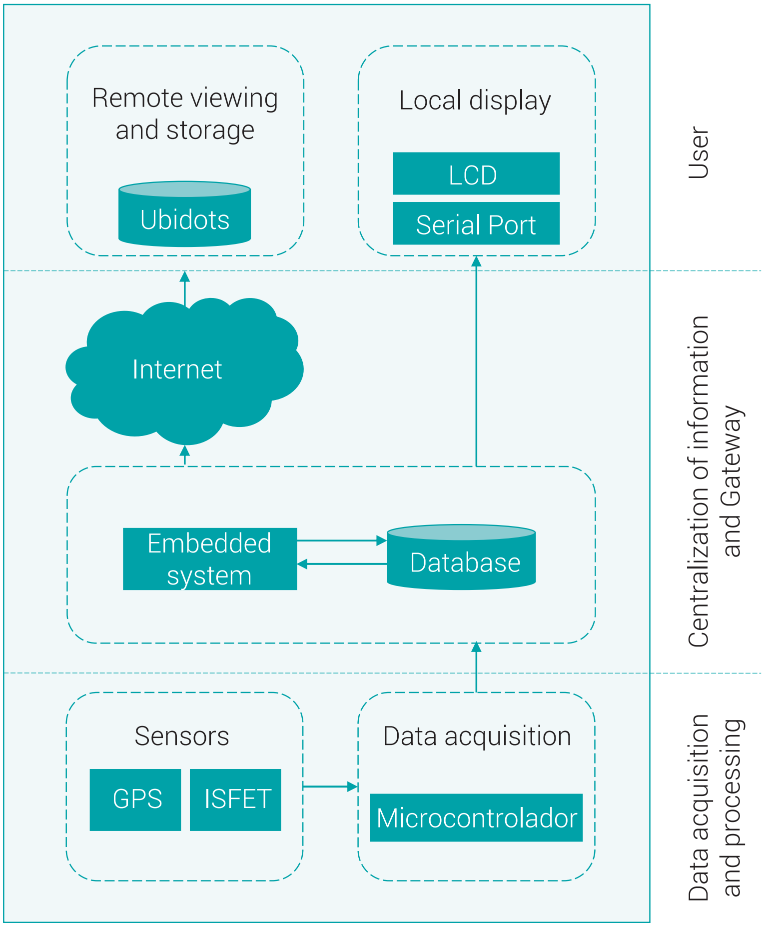

Figure 6. Generalized system architecture.
Source: Taken from [22].

These architectures have similarities in terms of the layers or modules that comprise them, thus revalidating the adaptation of the basic aspects required in architectures for precision agriculture: data collection, processing and analysis, and the presentation of the information to the end-user. It should also be noted that these proposed architectures are based on the use of: low-cost sensors with low energy consumption, easy to use Arduino and Raspberry Pi cards, free software to perform data mining, and cloud servers to store and visualize the information collected; thus allowing them to be applied in different crops in the Colombian territory as they use affordable hardware components and provide easy access to information remotely.

The IoT tools being used in the agricultural industry worldwide include cloud computing, agricultural applications for smartphones, robots for the crop harvesting process, IoT-based tractors, drones, and wireless sensors. All of these contribute to:

streamlining agricultural activities such as soil sampling and mapping through sensors that inform the user of the state and properties of the soil; crop irrigation with programmed and more efficient systems; precise fertilizer application according to the requirements of each crop zone; pest and disease control using sensors and image processing tools; and crop monitoring using monitors and yield maps [23]. Geographic Information Systems or GIS are also part of the application tools for precision agriculture. These are software with data storage and processing modules that have a defined geographic location, allowing for the analysis, monitoring, simulation and presentation of large amounts of data and information in the form of graphs, maps and multimedia systems. The application of this type of geoprocessing tool, with which crop spatial variability mapping can be performed, is of great help to manage agricultural production systems in areas with low productivity as they support decision making based on the state and requirements of the crop [24]. Such spatial variability of crops can be estimated by: continuous measurement methods such as yield monitors, discrete ones such as soil sampling, and remote ones such as the use of satellite imagery. Yield monitors consist of devices that perform periodic measurements of the flow of harvested material and, from this, calculate a crop yield value, generating estimates with which yield maps can be constructed, which graphically present crop yield data and thus allow for the identification of areas that require intervention to improve their production [25].

Another of the Agriculture 4.0 tools that can be more extensively applicable to the variety of crops in the country consists of the wireless sensor network, whose use and application extends to activities such as land monitoring, greenhouses, and automated irrigation systems; this is based on the measurement of environmental factors through the deployment of two types of sensor nodes: the source node, which performs measurements of the environment and collects this data, and the receiver node, which collects the information from the source node [26]. As presented in [27], through the use of an automation system composed of sensors and actuators, and monitoring and control software, better results are obtained when installing an automatic control system for a greenhouse crop, as this eliminates the uncertainty factors associated with manual crop control, as there is greater precision and control of climatic conditions and environmental variables, leading to better results in terms of crop growth and development. Complementary to the above, and taking as a reference the projects developed in several European countries, automated crop monitoring could also be considered as a technology applicable to Colombian agriculture to optimize the performance of some agricultural activities; it uses probes and sensors to collect data and, based on the interpretation of these data through indicators, alerts can be generated to determine the operation of actuators present in the crop, such as those used in some irrigation systems [28].

5. BENEFITS AND IMPLICATIONS OF AGRICULTURE 4.0 IN COLOMBIA

According to the Food and Agriculture Organization of the United Nations (FAO), the incursion of digital technologies in agriculture can generate benefits in three relevant areas: environmental, with systems that adapt to climate change, and by optimizing the use of resources required in agricultural production; economic, reducing production costs and increasing agricultural productivity; and social, allowing greater inclusion. For this, the country must have essential conditions for the proper application of digital technologies and to make way for the digital transformation of Colombian agriculture, such as ensuring the affordability of smartphones to farmers, improving infrastructure and connectivity to enable Internet access in different territories nationwide, training and educating the population on the use of ICTs and digital tools, and establishing policies and programs that promote the digital transformation of agriculture and agricultural development [29].

Traditional Colombian agriculture has always been affected by extreme weather events such as the El Niño and La Niña phenomena, which cause crops in various regions nationwide to be damaged by droughts, rains, or frosts. Given this, the implementation of Agriculture 4.0 practices in the country would constitute an efficient solution to face and adapt to climate changes, contributing to the reduction of the economic losses generated by them and affecting farmers. This highlights the need for the country to eliminate or minimize the existing technological and digital divide, and to invest in education so that society acquires digital knowledge that will not only be necessary and beneficial when applied in the agricultural context but will also contribute to the development and progress of the nation in general.

However, climate change and low agricultural productivity, global population growth, and with this the increased demand for natural resources and food, are fundamental aspects associated with agriculture and represent challenges to be faced with the application of technological practices of Agriculture 4.0 [14]; this, added to the challenges that have arisen when developing Agriculture 4.0 in other countries and that should also be considered for its advancements in Colombia, such as those related to low internet coverage and connectivity, the workforce that is not trained in technology, and aversion to it [23].

6. CONCLUSIONS

Although some projects and research related to Agriculture 4.0 have been developed in the country, to achieve its consolidation at the national level it is necessary to invest in technology and provide education and training to the actors involved in the agricultural sector so that they obtain the knowledge required to apply the technological models and tools in their crops according to their capabilities and requirements.

Given that, at the national level, the implementation of automation in the agricultural sector is scarce, the promotion of research in this area will contribute to the development of advances and projects that will strengthen the deployment of Agriculture 4.0 in the country. In this way, the application of Agriculture 4.0 practices in the country will allow farmers to optimize agricultural activities, improve crop productivity and take advantage of their potential, reduce costs and production requirements, be competitive, adapt to change, and produce sustainably.

To meet the challenges affecting the agricultural sector, it is necessary for Colombian farmers to gradually replace traditional production methods and adopt modern technological practices, allowing their activities to adapt to change and improve food production. In this way, the application of Agriculture 4.0 will contribute to strengthening and promoting the development of national agriculture.

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