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Review

Smart farming: A potential solution towards a modern and sustainable agriculture in Panama

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Abstract: Agriculture in the Tropical region, which includes Panama and other countries in the Caribbean and Latin America, has been developed using traditional tools with very little technology that has been designed and imported from countries with different environmental conditions. Some studies have suggested that the misuse of these tools may cause a negative impact on food production systems. Therefore, it is important to study, develop, and implement technological solutions that are appropriate for the conditions of specific regions and that help mitigating problems related to climate change and the production of food. One important solution is the implementation of technologies that interact with each other through the use of communication networks in Agriculture, known as “Smart Farming”. Many developed countries have promoted Research and Development (R&D) in Smart Farming, providing great benefits to their food production sector. The objective of this work is to document and provide an overview of the current situation of the Agriculture in Panama and the opportunities and challenges in the study, development, and implementation of Smart Farming as a technological solution in the agricultural sector in this country, in order to achieve an intelligent agriculture that allows a modern and sustainable food production. Finally, this paper provides some recommendations for the successful implementation of Smart Farming in Panama.

Keywords: agro-climatic variables; automation and control; ICT; IoT networks; protected agriculture; sensor networks

1. Introduction

It is known that the world population is increasing at an accelerated rate, and so is the demand for food. Studies have revealed that by the year 2050 the world population will be approximately 9 billion people, with a need for food increased by 70%. The main problem related to this estimated food demand growth is that, by the same year, it is expected that climate changes will significantly reduce the average food production, where developing countries such as Panama will be the most affected if the right actions are not taken [1].

At the present time, Panama has a service-based economy. Specifically, about 75% of the gross domestic product (GDP) is generated by activities developed by the Panama Canal, the Colon Free Zone, ports, banking, and tourism. Despite this, agriculture is one of the most important activities of the population, since it is one of the main sources of sustenance for low-income families. Fortunately, in a large portion of its territory, this country has environmental, water, and soil characteristics, suitable for agricultural production. According to the World Bank [2], from 1980 to 2015 the percentage of land with suitable conditions for agricultural activities in Panama increased from 25% to 30.4%. In addition, the population in rural areas has increased in recent years, which favors the agricultural activities carried out there. Specifically, from 1980 to 2017 the rural population in Panama increased from 980,445 to 1,344,337 inhabitants, which represents approximately 32% of the country's total population [3]. This increase in the amount of land to be cultivated and the human resource in rural areas contributed to the growth of the country's food production.

Most of the food produced in Panama is obtained from commercial farms and is destined for exportation. For example, according to data presented by the Ministry of Agricultural Development (Ministerio de Desarrollo Agropecuario, MIDA), from the period 2016 to 2017, a total of 77,009,317 quintals of the main national crops were obtained [4], where 67% came off industrial crops, 17% corresponded to fruit trees, 12% to grains, 3% to vegetables, and 1% to cucurbitaceous, roots, and tubers.

Recent studies indicate that Panama's food production index (i.e., the index showing the annual variations in food production, taking into account all edible products that nourish the human body) has increased from 1980 to 2016 [5], reaching a value of 115. Also, this country has a crop production index (i.e., the actual harvested production from the field or orchard and gardens, excluding harvesting and threshing losses and that part of crop not harvested for any reason.) [6], reaching a value of 88 in 2016. However, taking into account both indicators, Panama has one of the lower food and crop production rates compared to other countries of the region, such as Costa Rica, Nicaragua, Honduras, and El Salvador, as shown in Table 1.

Table 1. Comparison of the food and crop production indexes of the countries with the most agricultural activities in Central America [5,6].

	Food production index			Crop production		
	2010	2013	2016	2010	2013	2016
Costa Rica	114.3	126.3	131.0	109.7	124.8	130.3
El Salvador	105.1	116.1	119.8	106.7	108.4	111.3
Honduras	108.3	116.7	119.6	115.9	121.4	132.3
Nicaragua	119.9	131.4	128.5	107.7	128.9	137.7
Panama	107.4	117.4	115.0	91.5	92.5	88.0

Although the population in rural areas has increased, one of the main problems faced by agriculture in Panama is the lack of human resources for activities like food production and harvest. According to the World Bank [7], from 1991 to 2017 the percentage of employees who carry out agricultural activities in the country decreased from 38% to 19%. This percentage is one of the lowest compared to other countries of the Central American region, as observed in Figure 1. This decrease in labor to produce food and the rapid growth of the country's population has caused a significant deficit to meet food demand, mainly affecting the country's poor sector, which represents approximately 25% of the population. Therefore, seeking a short-term solution, the Panamanian government has proposed initiatives to import food; thus affecting the economy of the local producer. Another important factor that has significantly affected food production and the sustainable development of the agricultural sector in Panama (and other countries) is climate change [8, 9]. The agricultural production has been severely affected worldwide due to the changes in the climatic variables such as temperature, humidity, solar radiation, and precipitation, essential for the growth of crops. These environmental variations can negatively impact food security, investments, the location of crops, and productive activities, and also the families relying on these activities [10]. The last environmental performance index published in January 2016 shows that, in the agricultural aspect, Panama occupies the position number 145 out of 180 countries, where a score of 45/100 was obtained. One of the most highlighted problems was the condition of the fields in the rural area, having arid land, little rain, and low agricultural production.

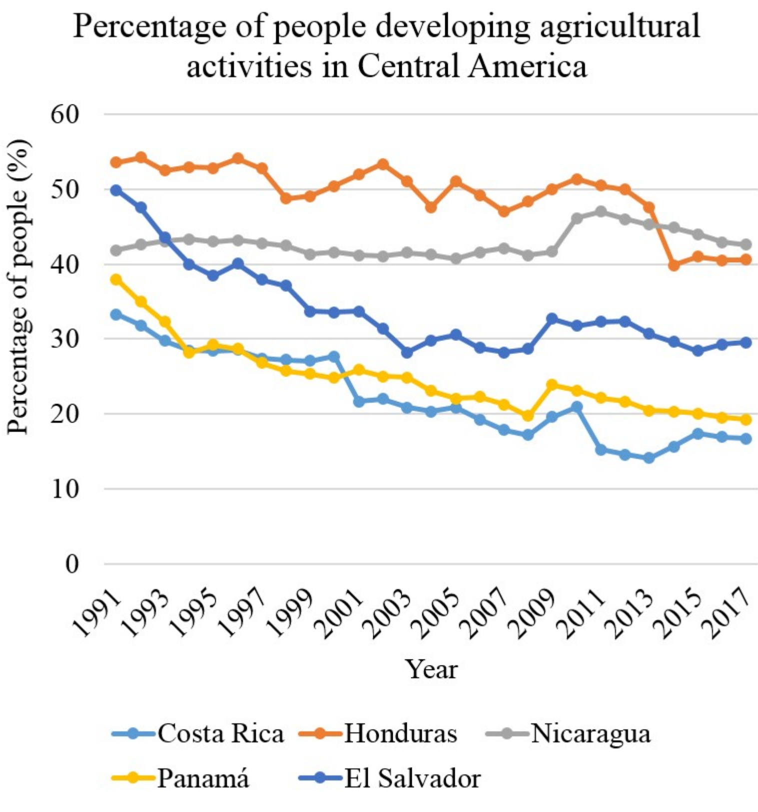

Figure 1. Percentage of people working in agricultural activities in Central America from 1991 to 2017 [7].

Furthermore, during the period from 2015 to 2016, Panama presented serious consequences on food production due to a water scarcity caused by the climatic phenomenon of "EL NIÑO" [11,12]. This phenomenon produced a severe drought because of the decrease in watersheds throughout the country. Motivated by this situation, the Panamanian government, in collaboration with the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) in Latin America, and with the support of the Central American Agricultural Council (CAC), presented the "State of the Art in Climate Change, Agriculture and Food Security of Panama", which includes the governmental framework and stakeholders involved in this issue. This document proposes to focus a large part of the research and projects in the country on the adaptation to climate change [13]. In addition, it shows the importance of promoting and strengthening initiatives to mitigate the impact of climate change. One of the proposed initiatives is to reinforce environmental education focused on climate change, dissemination of adaptation, and mitigation measures in the country [14,15].

The increase in the shortage of agricultural personnel and the effects of climate change have aroused great interest in the research community, especially in developed countries, to find solutions that help mitigate these threats. For this reason, many of these countries have proposed strategies to promote R&D for the development of technological tools appropriate to their characteristics and that help to reduce the effects of climate change, improve food production, and reduce the costs of inputs and labor. The integration of these solutions using communication networks to create more efficient agricultural systems is known as "Smart Farming", which aims to implement advanced technologies into traditional agriculture, in order to allow the producer to increase the sustainability and productivity of their crops using efficient tools and system resources [16]. Figure 2 shows some of the main technological solutions implemented in the agro-industrial sector using communication networks to interconnect each component.

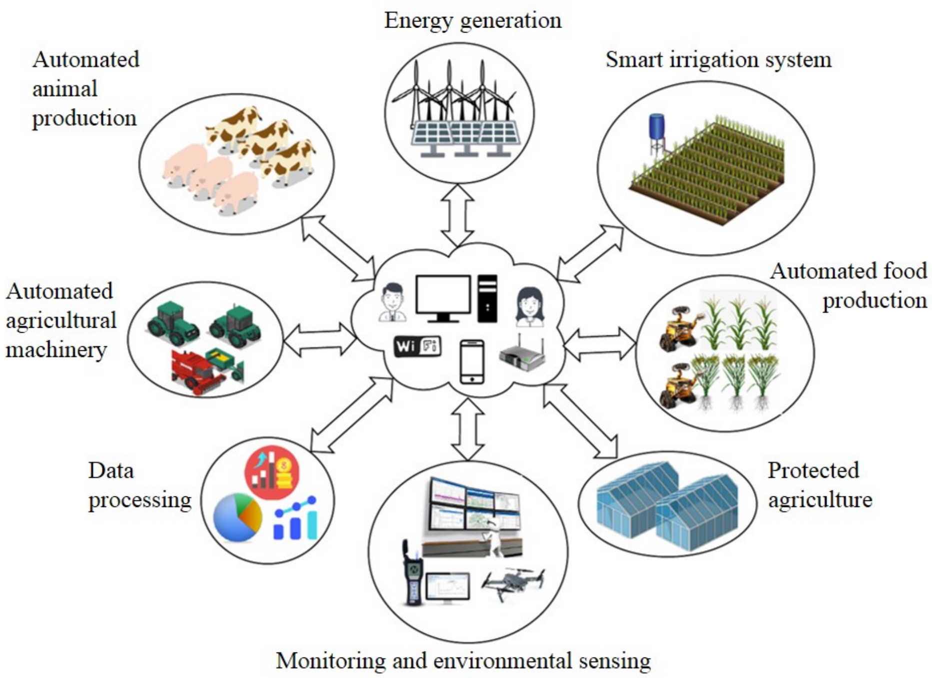

Figure 2. Technological solutions implemented in the agro-industrial sector. Created by E. Collado, A. Fossatti, and Y. Saez

In Panama and many other Central American countries, there is a lack of real interest in the development of adequate technologies for the production of crops in tropical conditions. This has resulted in the importation of inefficient foreign tools for agricultural production, with a high percentage of losses in agricultural systems, which represents one of the main problems faced by producers. Also, there is a low contribution of research on the impact of technologies on agribusiness in Panama. Therefore, the main objective of this work is to provide an overview of the opportunities and challenges in the study, development, and implementation of technological solutions for Smart Farming that are appropriate for the tropical conditions of the Panamanian region. This study could help mitigating problems related to climate change and the production of our food. The rest of this work is organized as follows: Section 2 describes the Smart Farming concept, Section 3 discusses different technological solutions implemented in food production, Section 4 analyzes the main challenges faced by the agro-industrial sector for the implementation of technology, and finally Section 5 provides conclusions and recommendations that can be very useful in the development of appropriate technologies for Tropical regions.

2. Smart farming

The new emerging technologies have allowed people to incorporate modern and advanced solutions that not only improve the productivity of the agricultural sector but also reduce costs, save time, improve the health and safety of the producer, increase product quality, and reduce losses within and out of the field. The implementation of technology by itself does not convert a conventional farm into an intelligent farm. Any system, machine, process, or domain is considered intelligent if, in addition to using state-of-the-art technology, it also has the capacity to adapt to meet any requirement, to sense changes in the surrounding environment, to infer conclusions based on results and observations, to learn from the results to improve their performance and anticipate preventing unwanted scenarios. In addition, Smart Farming needs “smart” consumers and producers with the ability to use the implemented technologies and to interpret the information generated in the system [16].

From the technological point of view, the Smart Farming is composed mainly of three interrelated fields of science and engineering: Biotechnology, Nanotechnology, and Information and Communication Technologies (ICT).

Biotechnology is the field of science that manipulates molecular, genetic and cellular processes through knowledge and techniques of biology. It has an important application in agriculture since it allows the producer to increase the productivity of the crops, implement a mechanism of resistance to pests and diseases, develop strategies to combat climate change, improve the quality and durability of the products during harvest or shipment [17]. Biotechnology can be very helpful as long as it is accompanied by reasonable biosecurity regulations and appropriate policies.

Nanotechnology is the field of science that allows the manipulation of physical and chemical characteristics by materials and equipment at a scale of 100 nanometers (nm) or less. This technology can be implemented in all phases of agriculture: production, processing, storage, packaging, and transport of products [18,19]. Among the most outstanding applications are:

- Precision cultivation.
- Improvement of the capacity of plants to absorb nutrients.
- Efficient and directed use of inputs.

- Detection and control of diseases.
- Mechanisms of resistance to climate change
- Food processing, storage, and packaging tools.
- Use of nanoparticles in animal sciences.
- Detection of environmental contamination.

The ICT are those technological tools that allow generation, processing, storing, and retrieving information through communication equipment and services [20,21]. In the agricultural sector, with the implementation and interconnection of different technological solutions through the use of ICT, producers will be able to replace conventional agricultural tools, obtaining a more intelligent, efficient, reliable, and sustainable system [22]. There are a large number of ICT solutions that can be applied to the agricultural sector such as precision agriculture, tracking, and animal tracking systems, food safety and quality management, food processing and manufacturing, consumer food awareness. These can be categorized fundamentally into five main types of technologies:

- Monitoring and environmental sensing.
- Specialized hardware and software.
- Telematics and positional reference.
- Communication systems (IoT, 5G, Wifi, etc.).
- Analysis of Information systems.

Following are some of the technological solutions commonly used worldwide in smart farms.

3. Technological solutions for the intelligent production of food

The rapid growth of technology in the twentieth century has allowed the development of a large number of technologies suitable for agriculture in rural and urban areas. With the introduction of technology in food production, there has been a positive change in many sectors of the population, mainly in the way of working of farmers, researchers, and all personnel in the agricultural sector. Among the main benefits of the implementation of technology in agriculture, we can mention:

- Better productivity in farming systems.
- Decrease in pollution.
- Efficient use of water, fertilizers, and pesticides.
- Reduction in food prices.
- Monitoring and operation in real time.
- Less environmental impact.

Among the technologies implemented in Smart Farming that present technical and economic feasibility in countries of Central America and the Caribbean are the greenhouses, micro-tunnel, and macro-tunnel structures, the monitoring, control, and automation systems, the intelligent irrigation systems, and the systems for analysis and care of water and soil, which will be explained in detail below.

3.1. Structures of greenhouses, micro-tunnels, and macro-tunnels

One of the most implemented solutions worldwide to combat climate change is the production of crops in a controlled environment. Agriculture in a controlled environment is developed in closed structures that allow adapting its micro-climate in order to obtain optimal climatic conditions for plant cultivation [23]. One example of agriculture in a controlled environment is vertical agriculture, where production is developed inside buildings, in totally enclosed environments, and with a high degree of technology to control all weather conditions, leading to a high production cost. Another variation of agriculture in a controlled environment is the protected agriculture, which uses special structures to protect the crop from adverse factors such as wind, rain, solar radiation, and pests. The protected agriculture is not totally closed and allows the moderate passage of light and wind for the development of the crop. The cultivation under protected agriculture has allowed the producers to obtain high-quality products and higher yields in any period of the year. In addition, it lengthens the cultivation cycle and allows production in the most difficult times of the year, obtaining better products and prices [24,25]. With the help of ICT, monitoring systems, control, automation, and analysis of agro-climatic variables necessary for the efficient production of food in these structures have been incorporated. Examples of most commonly used structures in protected agriculture are greenhouses, micro-tunnels, and macro-tunnels, which are briefly described below [26].

The greenhouses are closed, tall structures, covered with transparent materials (plastic, glass, fiberglass or corrugated sheets of polycarbonate), that allow creating a great diversity of micro-climates according to the needs of the crop. Depending on the structural design, they are classified in flat greenhouses or parral type, scraper type, asymmetric, chapel, double chapel, tunnel or semi-cylindrical type, glass or venlo type, and mesh or shaded houses. The use of greenhouses allows the control of temperature, humidity, solar radiation, pests, and other environmental factors, thus promoting the development of plants.

The micro-tunnels are small, simple, easy to install, and economically accessible structures that support a mesh that provides temporary protection against radiation, rain, wind, pests, and diseases in early stages of the crop development.

The macro-tunnels are medium-sized structures generally constructed with bamboo arches, PVC pipes or galvanized iron, covered with one or more layers of greenhouse-type plastic, agro-textile or anti-insect mesh. It can be used in all stages of crop development and protects the crop against radiation, rain, wind, pests, and diseases. As a preliminary phase to the structure installation for protected agriculture, it is advisable to consider three determining aspects: A study of the installation area, the selection of the infrastructure, and the study of soil, water, and wind [27]. The factors that can be investigated for the installation of a greenhouse are especially:

- Climatic conditions required by crops: It is important to analyze the absolute minimum temperature levels greater than zero degrees Celsius (0 °C), the absolute maximum temperature (Tmax), the number of hours of insolation, the minimum temperature limit of the soil, the threshold for the night temperature, and the relative humidity. Optimal adaptation is achieved by knowing the environmental conditions that are generated in the exterior and interior of the structure.
- Favorable external conditions to install the structure: It is important to know in advance the altitude, temperature, rainfall, topography of the land, wind speed, water availability, water quality, accessibility, availability of labor.

Panama, like other countries in the tropical region, has climatic conditions that favor the use of protected agricultural structures. Currently, some Panamanian producers have empirically implemented various protected farming structures such as greenhouses, vegetation houses, micro-tunnels, and macro-tunnels.

3.2. Monitoring, control and automation systems

In conventional agriculture, food is produced using mainly traditional techniques with little degree of technology and information on the behavior of the environment, which results in a production system with limited yield and serious problems in the crop. Among the most common problems there are dehydration and drowning plants, lack of nutrition, asphyxiation due to excess temperature, sunburn in plants, pests, among others.

Due to the rapid technological growth in recent years, the agricultural sector has evolved to provide the producer with a protected environment with monitoring, control, and automation technologies that allow obtaining information and influencing (in real time) on various environmental factors that directly affect production, development, and quality of the crop.

The monitoring component allows detecting variations of different factors with respect to some initially programmed values. These factors can be observed through a system composed mainly of a central entity to collect information and a network of sensors and/or RFID tags. The information generated will allow the producer to know every aspect of the farming system in real time [16]. These information systems are commonly designed using wireless communication technologies due to their low cost, easy installation, freedom of movement, and characteristics of the farming systems. The four communication standards available and most suitable for Smart Farming are R, ZigBee, Bluetooth, Wibree and WiFi links. Table 2 shows some of the factors that are normally analyzed within systems for protected crops. In addition to the monitoring system, a smart farm must also have a central controller that works as a control and automation system that processes the information coming from all the other components and assigns functions to the other actuators of the system. These functions are directly related to the decision made by the intelligent system based on the variations detected by the sensors. A common example of a function is activating and deactivating the irrigation systems based on the sensed environmental conditions, the water needs of the plants, and the decision of the central controller.

Table 2. Environmental factors monitored in intelligent crop systems [16].

Component	Environmental factor
Environment	Temperature and humidity
	Solar radiation
	Precipitation
	Wind speed and direction
Soil	Temperature and humidity
	Conductivity
	Salinity
Plants	Temperature and humidity
	Carbon dioxide
	Hydrogene
	Photosynthesis

There is a wide variety of control and automation devices that can be implemented in environments for protected crops. For example, there are low-cost devices such as actuators, microcontrollers, PIC programmable integrated circuits, timer devices, and programmable relays. In addition to its low cost, these devices allow the operator to easily design and configure the desired system without the need for a high level of knowledge in technology and a high degree of investment. Many countries have proposed collaborative initiatives between the government and university centers to promote the development of technologies for the monitoring, control, and automation of the environment in farming systems. In Mexico, the Tecnológico de Monterrey proposed an innovative model that improves the quality and quantity of hydroponic crops in the region, while facing the challenge of sustainability [28]. This approach is based on the development of intelligent systems to achieve the automation and control of the micro-environment in support of the daily tasks of the farmer. The application of control techniques using fuzzy logic helps the greenhouse to regulate environmental variables to generate a microclimate that guarantees the optimal development of the crop. In Israel, the Technological University of Israel proposed the design and implementation of a prototype of a control and monitoring system that monitors the temperature and humidity homemade crops in a greenhouse [29]. In Ecuador, the Universidad Politécnica de Quito developed a predictive remote control system for a greenhouse using clouding technology, whose results were able to stabilize the appropriate parameters for the crops, generating advantages that were not available in the traditional system, avoiding crop losses and diseases caused by high temperatures and humidity [30].

3.3. Smart irrigation systems

Another important aspect is the implementation of tools to efficiently manage water in agricultural activities. The use of inefficient techniques of mass irrigation in agriculture, such as sprinklers and water channels, has caused a considerable increase in the demand for water and a significant waste of the vital liquid. According to the results presented by the Food and Agriculture Organization of the United Nations (FAO), in the last years, approximately 69% of the total water extracted in the world is destined to agriculture. Also, due to rapid population growth and high demand for food, many countries are facing water shortages. It is estimated that by 2030, more than 60% of the population will live in urban areas that will demand an increasing proportion of the water extracted. This has motivated the development of automated irrigation systems that facilitate an adequate automatic water supply, thus optimizing the use of water in the food production process. Automated irrigation systems are commonly divided into [31–33]:

- Systems without feedback: Those systems that operate under predefined conditions without the need to monitor. They are usually conditioned by the time and volume of water.
- Systems with real-time feedback: Those systems that are operated based on the monitoring of at least two input signals. Some of the factors that are used are soil moisture, rain, temperature, evapotranspiration, radiation, among others.

These systems are usually composed of a central computer, high-precision sensors, actuators, and a software interface that allows controlling the water supply and monitoring it in real time [34,35]. Basically, the software identifies the amount of water needed, based on the plant characteristics and the sensed environmental conditions. Then, it sends that information to the central controller, which assigns certain functions to the system's actuators. Many of these systems have included Internet-based technologies that allow the irrigation system to operate from any mobile device [36,37]. Advances in science and mathematics have made it possible to include optimization procedures that not only optimally control water distribution but also allows maximizing the total efficiency of the irrigation system [38–41]. This shows that there is a concern in recent years to develop efficient technologies for the efficient use of water in agriculture.

3.4. Systems for analysis and conservation of water and soil

Soil and water are a crucial part of a farming system because they provide the ecosystem necessary for the production of healthy food. Therefore, it is important that research is conducted to develop strategies that allow the good management and conservation of them. When planning and implementing an agricultural production project in a controlled environment, it is essential to know the substrate-soil-water relationship. This is because, in this system, crops require intensive care because they grow under artificial conditions [42]. Also, the low quality of water for the crop can cause salt accumulation in the root zone, loss of soil permeability due to excessive leaching of sodium or calcium, the presence of pathogens or contaminants that are directly toxic to plants or for which they consume them. These contaminants in the irrigation water make the soil unfit for agriculture, and potentially affect the acceptability of the agricultural product for sale or consumption. Among the main criteria of irrigation water quality that are taken into account are the tolerance of crops to the concentration of sodium and phytotoxic trace elements. Sodium in irrigation waters can adversely affect the structure of the soil and reduce the rate at which water moves to and through the soil. Sodium is also a specific source of damage to fruits. Phytotoxic trace elements such as boron, heavy metals and pesticides can impede the growth of plants or make the culture unfit for human consumption or other intended uses [43]. Initially, the fields of physics, biology, and chemistry were in charge of the study of the biogeochemical and physical characteristics of soil and water. These studies allowed better managing resources, examining the function and health of soil and water, optimizing food production and mitigating climate changes. With the passage of time, farmers have incorporated technologies that have allowed them to take good care of the soil, water, and the surrounding environment in a faster and more efficient way [44]. Some of these technologies are:

- Monitoring system for nutrient levels, temperature, humidity, pH and other factors in soil and water.
- Intelligent irrigation system to reduce losses.
- Global positioning system (GPS).
- Drone system with spectral fingerprints for remote analysis of soil and water.
- Precision agriculture systems to efficiently apply nutrients to soil and water.
- Remote systems for soil and water pollution analysis.

4. Opportunities and challenges in the implementation of technologies in the agricultural sector in Panama

In Panama, the accelerated population growth and the economy have increased the total food demand. Although the country has human resources and a large amount of land suitable for the development of agriculture, food production is being affected by climate change. One of the factors that have most affected the agricultural sector in recent years is the uncontrolled increase in temperature, which directly affects crops, livestock production, and health of the population. With regard to water resources, Panama has very good quality water, mainly during the rainy season. However, in recent years, there have been seasonal water deficits during the dry period. For example, Panama presented one of the worst water scarcity crises during the 2015–2016 period due to the climatic phenomenon of “EL NIÑO” [11,12], mainly affecting the food production in the central area of the country, and losses in agricultural production arose as a result of the decrease in river basin flows throughout the country. Additionally, the economic and population growth of Panama has caused an increase in water consumption every year in all sectors. In 2010, the agricultural sector used 446 million cubic meters of water, which represented 43% of total water consumption in Panama for that year.

Another problem faced by the country is the lack of control in urban development, which generates alterations in the water cycle, affecting the soil infiltration, and increasing surface runoff. Besides, there are very little studies on groundwater in Panama, due to the lack of precision tools and technologies that allow the monitoring of the number of existing aquifers, their recharge areas, and their yield potential. All this has caused the country to face a great challenge for the systematic, efficient and sustainable management of water in the face of the growing water crisis.

Another situation that exists in Panama is the change in land use. Approximately 1.8 million hectares of the national territory presents optimal conditions for agricultural development, however, due to the high demand for food due to rapid population growth, the actual use of land for agricultural activities has increased to 2.9 million hectares. This conflict in the territorial ordering has caused the degradation of the lands due to significant erosion processes, loss of fertility, and contamination. In this context, Panama also faces the challenge of producing more food on land destined for agricultural activity, in order to guarantee the productive and environmental sustainability of the soil. Panama must face the problem related to soil and water sources contamination, mainly caused by mining, agro-chemical use, the discharge of domestic and industrial waste, among other activities. Another great challenge faced by the agricultural sector of Panama is that the small number of human resources with the capability of solving agricultural-related problems. It is considered that if a country had at least one thousand scientists per million inhabitants dedicated to conducting research, this country would be capable of transforming and strengthening its economy, a figure that is far above the existing human resources in Panama.

Although the government is promoting initiatives to increase the number of scientists available to solve the challenges, there are many barriers that must be analyzed before taking any action. Some of them are:

- Most researchers have a high teaching load in universities or other education centers.
- Collaborative and multidisciplinary research is scarce.
- Reduced financial resources for the R&D projects.
- Lack of laboratories with specialized teams that allow researchers to continue the work they started in other countries and thus being able to maintain collaborative relationships.
- Lack of national postgraduate, masters, and doctoral programs that promote R&D to solve national problems.
- Difficulty creating job positions for young scientists.
- Lack of systems that allow sharing information between government institutions, private companies, and education and research centers.

In addition to the aforementioned problems, a large part of the highly educated researchers and most of the research centers are located in Panama City, where food production activities are not performed. This has created a distancing between the producer and the research centers that can offer a solution to specific problems. This lack of research and knowledge has led the producer to import technologies that end up to be inefficient because they were designed for different environmental conditions. For example, there are companies in Panama that have implemented large systems of protected agriculture that face various problems due to design deficiencies that did not contemplate the agro-climatic conditions of our region, the type of crop, and the geographical area to be developed, among other parameters. These structures are being operated on the basis of empirical experiences, where trial and error is the method of work used. This provokes that small and medium producers with limited financial resources refrain from investing in the implementation of new technologies.

5. Discussion

To solve the problems related to the agricultural sector, a priority action is to promote a State Policy on Science, Technology, and Innovation (STI), allowing the integration of governmental and private sectors for the generation and development of strategies that provide adequate solutions to the problems of the agricultural sector. An important initiative that is being developed in Panama is the National Strategic Plan for Science, Technology, and Innovation (Plan Estratégico Nacional de Ciencia y Tecnología, PENCYT) 2015–2019 [45] with the program "Science, Research, Technological Development and Innovation for Sustainable Development", which seeks to solve problems related to food security in the country. The objective of this program is the use of science and technology to mitigate national problems related to the disorderly growth of the population and urbanization; the environmental changes; food, water, energy, and cyber security; the conservation of biodiversity and ecosystems; the appearance of new diseases and the reappearance of other diseases; the confrontation of natural disasters; the need to reduce social inequalities and eliminate poverty and hunger by improving the living conditions of the world's population. Among the proposed lines of work to overcome these challenges we can mention:

- The line of action of "Thematic networks for sustainable development".
- The line of action of "Support for the strengthening of the agricultural sector".
- The line of action of "Support for research for adaptation to climate change".
- The line of action "Preparation of human resources to meet the prioritized demands for the development of science and technology in the country".

With these initiatives, the government of Panama hopes to achieve the following objectives in the medium and long-term:

- To establish a permanent dialogue with multidisciplinary groups on science and technology for sustainability.
- To promote research on current production systems and their relation to water and soil resources in a regionalized territorial vision and with a view to guaranteeing food security.
- To support the implementation of the medium and long-term energy policy and strategy.
- To contribute to the evaluation, monitoring, and mitigation of climate change.
- To contribute to the scientific and technological development of the country, from a sustainable development approach.
- To understand the dynamics and social behavior in front of the problems and the solutions of the development.
- To contribute to the implementation of a sustainable urban development strategy.

Today, the level of implementation of the initiatives for the agricultural sector of the PENCYT 2015–2019 is still incipient, mainly in the lack of a solution to other structural problems such as:

- Optimal of water for agriculture.

- Prevention strategies on issues of climate change.
- Excessive food imports.
- Loss of the trade balance of the sector due to the import approach.
- Food HUB that mainly benefits producers in other countries.
- The inclusion of national producers in the development of policies and strategies that really benefit the Panamanian agricultural sector and their families are lacking.

According to data obtained from the World Bank [46,47], the country has achieved a notable increase in the number of subscribers of mobile cellular and fixed broadband service customers, as shown in Figures 3 and 4. As observed, in 2017, for every 100 inhabitants, Panama presented approximately 150 subscriptions of mobile cellular telephony and 10 subscriptions of fixed broadband service. This places Panama among the countries with the largest number of subscribers to telecommunications services. In addition, Panama also presented a considerable growth in the number of secure servers for the transfer of information in recent years [48], reaching a figure of more than 2000 secure servers in 2017, which is much higher than neighboring countries, as shown in Figure 5. This advance in the telecommunications sector in Panama has led to the development of interesting initiatives for the implementation of the Strategy for the Development of the ICT Sector 2025, called PANAMA HUB DIGITAL. This project will allow the development and implementation of communication technologies that will help to strengthen all economic sectors of the country, especially the agricultural sector. These technological advances will provide producers and decision makers with the necessary tools for the valuation and conservation of the agricultural sector, through knowledge of genetic diversity, sources of resistance, biology, and behavior of animals and plants, capacity to resist climate changes and technologies applied to improve production.

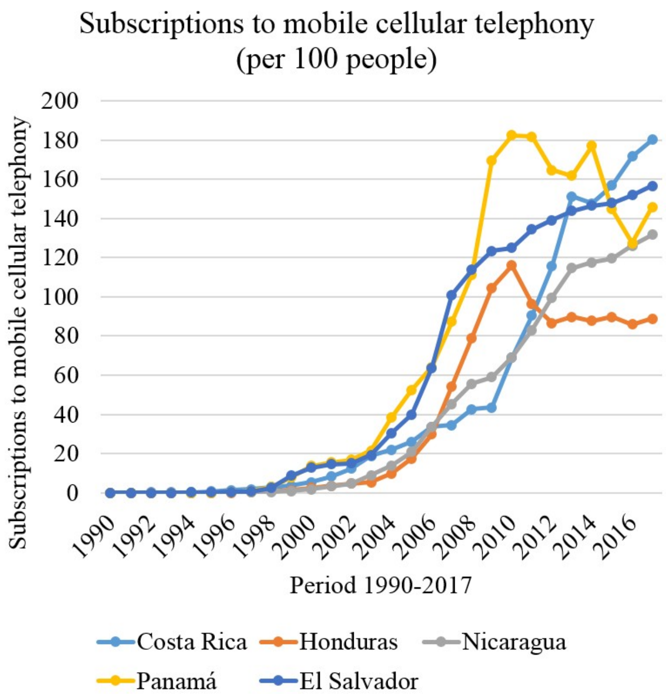

Figure 3. Number of subscriptions to mobile cellular telephony per 100 people in Panama from 1990 to 2017 [46].

The use of technological tools in the agricultural sector through Smart Farming can help mitigate losses in the crop due to the unstable situation of climate change. The development of Smart Farming in Panama will certainly positively impact the agricultural sector, which is why the initiatives proposed in the PENCYT 2015–2019 need to be supported by the collaboration between the public and private sectors and educational and research centers. This initiative would make the development of proprietary technologies a national priority issue, which would promote the creation of specialized research centers in Smart Farming near the food production region, equipped with tools to provide the Panamanian producer with optimal technological solutions to our characteristics. Specifically, these centers would have the capacity to generate high impact R&D projects in the development of technologies for Smart Farming to develop protected environment systems, develop solutions for the optimization, control and automation of agricultural production systems, determine and evaluate the agro-climatic characteristics within crop systems, carry out studies on soil and water quality, compare the performance of the automated versus non-automated agricultural production system, study the impact of the appropriate use of appropriate technologies on production and capacity development and transfer of results to researchers, students and horticultural producers in the country.

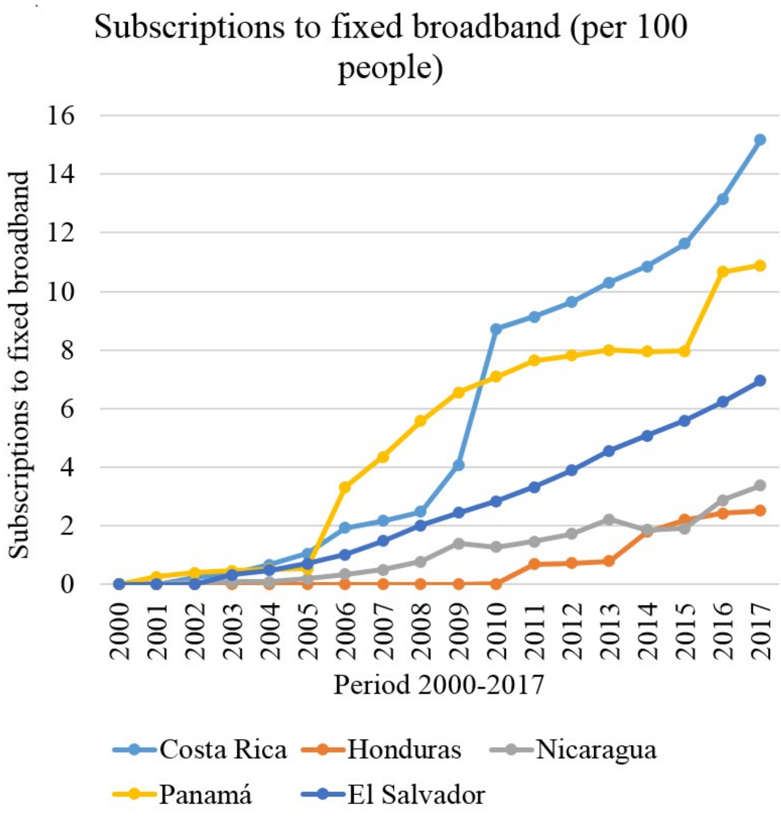

Figure 4. Number of subscriptions to fixed broadband per 100 people in Panama from 2000 to 2017 [47].

The equipment of these research centers and the strengthening of the human resources of the country would help the producer to solve important questions when investing in technologies for smart farms such as:

- What is the proper structure in height and design for tropical crops?
- What is the appropriate ventilation in the area to develop the structure?
- Are current imported designs suitable for tropical crops?
- What is the incidence of pests and diseases in tropical crops?
- Does automation increase crop productivity, to what extent?
- Is the water quality (rain, surface or underground) in Panama suitable for the development of hydroponics?
- What is the most appropriate and effective material for crop structures?
- How can the optimum temperature and relative humidity be obtained?

The main impact that the development of Smart Farming in Panama will have will be evident in the improvement of quality and crop production. From the socio-economic point of view, the implementation of smart farms will provide efficient technological solutions using ICT to improve the production and quality of food, which will increase production per m^2 and avoid economic losses in the agricultural sector. With this, the consumer will be able to obtain products of better quality and at a lower cost. On the other hand, monitoring, control, and automation technologies would help to mitigate problems related to climate changes, which are one of the main factors that affect food security. Betting on the development of R&D in agro-technologies would help to reduce the ignorance faced by a large part of the producers, especially the producers of family farming, commercial and investor who wish to work in this activity. In addition, there are the benefits in science and education, like strengthening the knowledge in Smart Farming, providing technological tools for the study of the impact of climate change, a greater capacity to develop R&D in design, implementation, and validation of agro-technologies, and dissemination of indicators throughout the national territory that allow to know the possible factors that affect the products, and promoting innovation and validation of appropriate technologies for our region. During the training of human resources in this field of research, the number of students and researchers interested in doing scientific and technological theses in the area of telecommunications and technologies applied to the agricultural sector can increase. The competences created are new for the country, which are of great importance for the study of the modernization of agriculture and its impact on the quality of life of man and the economic growth of Panama, mainly in the rural area of the country where the agricultural activity is one of the main sources of sustenance.

When implementing Smart Farming, it is important not only to highlight scientific and technological advances but also to take into account the social and environmental aspects that this entails [49,50]. For example, a large part of the population in Panama that carries out agricultural activities have low levels of education, which makes it difficult to adopt technologies. Therefore, it is important to study human behavior and to develop social innovation strategies that allow the adoption and friendly inclusion of technologies in rural areas. In addition to human behavior, it is essential to consider aspects such as agricultural characteristics of the region, climate changes, market characteristics, regulations, socioeconomic impact, among others. Although the implementation of Smart Farming would mean a great challenge for Panama, due to the economic investment it requires, the modernization of agriculture would positively impact the production and quality of food, the generation of job opportunities, the environmental sustainability, the food security, the cost of food, and the economy of the country. This would, in the medium and long-term, guarantee a sustainable future by responding to basic needs, offering a better quality of life, and minimizing the use of natural resources and emissions, without compromising needs of our future generations.

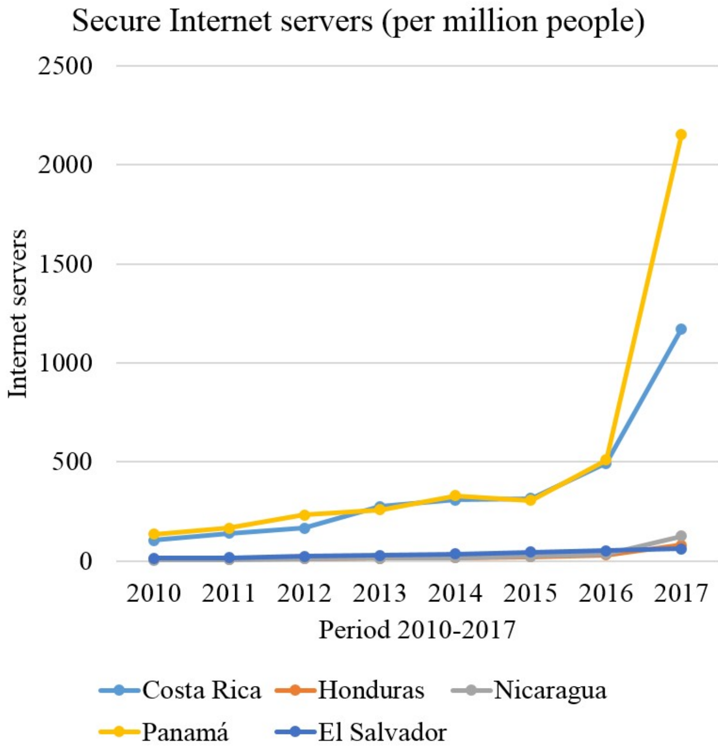

Figure 5. Number of servers with encryption technology for secure information transfer over the Internet in Panama from 2010 to 2017 [48].

6. Conclusions

This paper addresses some key challenges associated with the implementation of Smart Farming in the agricultural sector in Panama. The political initiatives developed to support the agricultural sector and the rapid technological growth in this country, have created the ideal scenario for the implementation of Smart Farming on a large scale throughout its national territory. However, the deployment of this technology could be hard and requires large research efforts to tackle the challenges. Therefore, it is important to strengthen research centers and institutions with specialized human resources and equipment to successfully develop a project that not only benefits Panama but also all other countries that have a commercial relationship with it. In addition, the implementation of Smart Farming must not only take into account the technical aspect but also consider environmental, economic, and social aspects to ensure a friendly adoption by the agricultural sector and society in general.

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Conflict of Interest

The authors declare no conflict of interest.

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