EXPERIÊNCIA NO USO DE SISTEMAS EFICIENTES DE IRRIGAÇÃO SMART AGRO 4.0 ATRAVÉS DA TECNOLOGIA IOT PARA ALGODÃO EM DOIS DEPARTAMENTOS DE PERU

EXPERIENCE IN THE USE OF EFFICIENT SMART AGRO 4.0 IRRIGATION SYSTEMS UNDER IOT TECHNOLOGY FOR COTTON IN TWO DEPARTMENTS OF PERU

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Resumo

Nos últimos anos, a agricultura tem sido afetada pelas consequências da mudança climática e requer inovações tecnológicas para enfrentar os diferentes desafios relativos à produção, aos custos e à gestão eficiente dos recursos naturais. No Peru, existem 2,3 milhões de produtores agrícolas, com cerca de 10.000 agricultores familiares atualmente dedicados ao cultivo do algodão, concentrados principalmente nos vales costeiros dos departamentos de Ica, Lima, Lambayeque, Ancash, e Piura. Para enfrentar o desafio da mudança climática e da inovação e melhorar a produção de algodão e o uso dos recursos naturais, foi implementado um piloto de irrigação eficiente usando IoT, tensiômetros e estações meteorológicas com apoio da Fundação Telefónica e FAO no âmbito do Projeto +Algodão (Projeto de Cooperação internacional entre Brasil, FAO y 6 países latino-americanos). Este estudo visa analisar e comparar os resultados do uso desta tecnologia entre 2018 e 2019 durante três campanhas agrícolas, medindo o uso eficiente da água e rendimento do algodão e cultivos associados em comparação com os produtores sem esta tecnologia em três áreas do Peru. Como resultado, a produtividade do algodão aumentou em 53% e do feijão entre 18 a 29% em comparação com propriedades vizinhas, e otimizou o uso da água, gerando uma economia de até 20% na irrigação e uma rentabilidade de 50% no cultivo. Também permitiu o controle do crescimento das plantas e, portanto, o planejamento do tempo de colheita da propriedade. Esta tecnologia mostrou-se útil para os agricultores e inovadora em comparação com as técnicas de irrigação por inundação utilizadas no setor do algodão peruano. Entretanto, seu alto valor exige que as instituições nacionais incorporem financiamentos e planos associativos, para dar sustentabilidade ao longo do tempo. Neste sentido, o intercâmbio de conhecimentos e o trabalho de cooperação internacional podem apoiar o estabelecimento de medidas apropriadas para a implementação desta tecnologia.

Palavras-chave: Algodão, Peru, irrigação, IoT, agricultura 4.0

Abstract

In recent years, agriculture has been affected by the consequences of climate change. It requires technological innovations to meet the different challenges regarding production, costs, and efficient management of natural resources. In Peru, there are 2.3 million agricultural producers, with around 10,000 family farmers currently dedicated to cotton cultivation, concentrated mainly in the coastal valleys of the Ica, Lima, Lambayeque, Ancash, and Piura departments. To address the climate change and innovation challenge and improve cotton production and the use of resources, a pilot of efficient irrigation using IoT, tensiometers, and weather stations was implemented between Telefónica and FAO within the framework of the +Cotton Project. This study aims to analyze and compare the results of using this technology between 2018 and 2019 during three agricultural campaigns by measuring water use and yield compared to producers without this technology in three areas of Peru. As a result, cotton yields increased by 53% and beans between 18 to 29% compared to neighboring farms, and optimized water use, generating savings of up to 20% in irrigation water and profitability of 50%. It also enabled control of plant growth and thus planned farm harvest time. This technology proved helpful for farmers and innovative compared to the flooding irrigation technics used in the Peruvian cotton sector. However, its high value makes it necessary for national institutions to incorporate financing and associative plans, which may hinder its

sustainability over time. In this sense, the exchange of knowledge and the work of international cooperation can support the establishment of appropriate measures for implementing this technology.
***Keywords**: Cotton, Peru, irrigation, IoT, 4.0 agriculture*

1. Introdução

In recent years, agriculture has been affected by the consequences of climate change and requires technological innovations to meet the various challenges that arise in terms of production, costs, and efficient management of natural resources. In the next thirty years, it is estimated that developing countries will need to produce almost 50% more food, fiber, and biofuels than in 2012 to meet global demand, which translates into 165 million hectares in 2050 to meet the needs of the population, implying a global increase of 30% in production. All this in combination with lower growth of arable land and greater water scarcity because of climate change (FAO, 2021). On the other hand, according to the World Bank, the world population is expected to reach 9.7 billion people (World Bank, 2022) and the demand for food is expected to increase by 59% to 98% (Valin et al, 2014). To achieve this, it is key to incorporate new practices that allow more efficient use of critical resources such as water and soil, among which water is of vital importance since the level of agricultural production depends on 70% of this resource (Betancourt et al, 2017).

Faced with this need for new ways of producing and using water resources, technological development for the efficient use of irrigation water initially focused on conduction and irrigation systems, seeking to improve the timeliness and precision of irrigation. However, a new generation of technologies has arrived in agriculture, being observed in the last decade, the revolution in cyber-agriculture, known as Agriculture 4.0, thanks to the introduction of big data analysis, cloud computing, cheap and improved sensors and, mobile broadband communication (FAO, 2018; Abbasi et al, 2022). One of the technologies involved is known as the internet of things (IoT), which generally refers to scenarios in which network connectivity and computational capacity are extended to objects, sensors and everyday items that are not usually considered computers, allowing these devices to generate, exchange and consume data with minimal human intervention.

In Peru, there are 2.3 million agricultural producers, and, of this total, 10,000 producer families are currently dedicated to cotton cultivation, mainly concentrated in the coastal valleys of the departments of Ica, Lima, Lambayeque, Ancash, and Piura (FAO and ABC/MRE, 2017). This is in addition to the fact that 40% of its territory is considered arid or semi-arid and is home to more than 80% of its population (Lentini, 2021). In the prospective analysis of the Multiannual Sectoral Strategic Plan (PESEM 2015-2020), one of the trends identified is the inefficient and unsustainable use of water resources, which contributes to a decrease in water reserves and longer periods of minimum flow in rivers, as well as a growing demand for water resources for agricultural use in general and export agriculture, which could increase conflicts over the use and quality of water resources (mining, agriculture). On the other hand, there is greater interest in water resource management and the use of new technologies (MINAGRI, 2015).

To address this growing need, Telefónica Peru and the Food and Agriculture Organization of the United Nations (FAO), through the +Cotton Project (FAO, the Brazilian Cooperation Agency and the Ministry of Agrarian Development and Irrigation) signed a cooperation agreement for the development of field pilots to bring innovation, digitization and data analysis of cotton crops and food items. In total there were five (5) plots in the three (3) different stages of the project developed between 2018 and 2020 in the departments of Pisco and Lambayeque. Each pilot considered the installation and operation of an intelligent solution for agricultural production developed by Telefónica I+D, which allows for delivering a detailed recommendation report of efficient use of irrigation water, through a kit of 3 digital tensiometers with depths of 20 cm, 40 cm and 70, with connection to the cloud and its subsequent correlation with meteorological data, through a customized mathematical model. The objective of this study is to analyze the performance, yield, production, and water savings in the Demonstration Technical Units implemented by the Project, compare them with the results of neighboring producers, and analyze the factors that are critical for the implementation of this type of technology.

2. Methodology

Smart Agro 4.0 is a complete system for monitoring, controlling, and predicting agronomic variables. Using remote sensors and artificial intelligence from a mathematical model, it predicts how much water resource needs to replenish in the fields to optimize water use, improving the quality and quantity of the farm's final production.

The pilot was developed in Peru, specifically in Ica and Lambayeque, within the cooperation framework between the Telefonica Foundation and the Food and Agriculture Organization of the United Nations, through the Trilateral South-South Cooperation +Cotton Project (ABC/MRE – FAO – Countries).

The research was carried out in the Demonstration Technical Unit (DTU), which is similar to a commercial-sized production field, in which the Project + Cotton in which the following innovations and good practices were applied: (i) adequate preparation of soil including subsoiling, (ii) use of the certified seed, (iii) sowing mechanized, (iv) fertilization based on soil analysis, (v) efficient irrigation that includes technology promoted by Smart Agro 4.0, (vi) integrated pest management, based on evaluation, privileging the use of biological controllers and other preventive measures; and (vii) control of plant growth.

The innovation consists of 5 main components:

- field sensors (tensiometers and weather station);
- mobile connectivity (3G and 4G data plan for sending and receiving data to the cloud);
- web platform (graph analysis, irrigation booklet and monitoring);
- analysis and accompaniment of the agronomist expert (analysis, monitoring, and recommendations) and,
- irrigation report (a report that gathers the information collected).

Equipment and platform used:

a) Kit of digital tensiometers, which measure the tension of humidity generated in the root zone of crops. In this case, were selected at 20, 40 and 70 cm of depth. These kits are connected to the cloud, recording data every 15 minutes.
b) The ATMOS 41 meteorological station, is a modular microenvironment station that has no moving parts and is slim and tubular equipment. It measures 12 meteorological variables. It is also connected to the cloud. This station was only available from August 2019.
c) Smart Agro Peru 4.0 Platform, under the principle of big data, uses, stores and organizes the information generated by both equipments: tensiometers and meteorological stations.

d) Optimal Crop©: analyzes irrigation behavior and water consumption in the field based on soil moisture data. It provides graphical and analytical irrigation information. It integrates with the main sensors and delivers a detailed analysis of irrigation over the required time.
e) Bacsoft Communication Controller: offers a method of remote control and monitoring, through support for various interfaces, protocols, and devices; can store data in the Bacsoft IoT cloud; and allows the development of non-coded applications to build IoT applications for mobile devices, web and control centers.

In the field, weather stations capture meteorological data of the area and the tensiometers installed in the field, at three depths (20, 40 and 70 cm) make continuous monitoring of the soil humidity, collect real-time information and send it through 3G/4G networks to the Bacsoft remote controller platform, which stores it in its cloud and sends it to the Optimal Crop software, to analyze the irrigation behavior and water consumption in the field. It delivers detailed graphic and analytical irrigation information, which, together with technical monitoring and validation of the information, allows for remote decision-making, monitoring, and water resource usage management based on the field's real requirements.

International technical assistance was provided by an expert from Telefonica company, who analyzes and systematizes the data, validates the use of technology for cotton and bean crops and advises the local technical team to make irrigation decisions. There was also a local technical team, made up of a technician from the +Cotton Project and another from the Ica Regional Directorate of Agriculture, who carried out agronomic monitoring and evaluation and integrated management of crop pests, including irrigation scheduling.

With the data obtained, the variables of yield per hectare for cotton and beans, water use per hectare and critical stress for irrigation definition were calculated.

3. Results

The research was carried out during the 2018/2019 and 2019/2020 campaigns. There were 3 DTUs implemented between the +Cotton Project and Telefonica, two located in Pisco and one in Lambayeque, with an area of 4 hectares, different irrigation systems and the tensiometer kit stipulated for the research. Table 1 below details the three pilot areas implemented.

Table 1. Pilots implemented in Peru in the departments of Ica and Lambayeque

	DTU Victor Muñoz	**DTU Justo Córdova**	**DTU Tito Cubas**
Location	Pisco	Pisco	Lambayeque
Irrigation system	Drip	Gravity	Drip
Pilot area	4 hectares	4 hectares	2 hectares
Soil type	Sandy loam, slightly saline. Stones from 40 cm.	Medium sandy loam. Slightly saline. Presence of calcareous formations and superficial water aquifer (1-1.2 m).	Clayey loam. Presence of slightlysaline sectors.
Equipment	A kit of 3 depths (20 cm, 40 cm, and 70 cm) of digital tensiometer with connection to the cloud.		

Source: +Cotton Project

The project showed an increase in crop yields in the ratio of quintals per hectare, compared to neighboring farms that did not have the technology. In the first season of cotton, in all cases, there were higher yields than producers near our DTU (Demonstrative Technical Unit).

Table 2. Yields of the cotton crop, Season 2018-2019 (QQ/h)

Location	**Pisco – Ica**		**Muy Finca - Lambayeque**
DTU	**DTU Víctor Muñoz**	**DTU Justo Córdova**	**DTU Tito Cubas**
Average cotton yield (qq/ha) *	45.3	88.5	63.5
Yield nearby farms	41	50	37
Yield Increase (%)	10%	77%	72%

**qq=46 Kg*
Source: +Cotton Project

In this case, the yield obtained, although superior to that of the neighboring producers, is still below its yield potential, which is estimated between 100 to 120 QQ / h.

Second Campaign

In the second season, before cotton cultivation, rotation crops were planted. In the case of Pisco, common beans (Phaseolus vulgaris L.) and in the case of Lambayeque, cowpea beans (Vigna unguiculata (L.) Walp.) were used. Both crops are very important for the food security of the farmers' families and for their contribution to improving soil fertility, since they are crops that help to fix nitrogen, among other benefits of crop rotation. Yields were evaluated in these plots using the results of neighboring producers as a control. It is observed that in both cases there was also an increase in productivity between 18 and 29%. Table 3 shows the yields for the rotation crops planted in the 2019/ 2020 season.

Table 3: Yields of the beans crop, Campaign 2019 -2020 (Kg/h)

Locations	**Pisco - Ica**	**Muy Finca - Lambayeque**
DTU	**DTU Justo Córdova**	**DTU Jorge Fuentes**
Culture	Common bean	Cowpea bean
Average produced bean	1,800	1,100
Production nearby farms	1,400	930
Yield Increase (%)	29%	18%

Source: +Cotton Project

In the case of cotton, the second season for the 2019/2020 cycle was planted in October and harvested in May 2020. This season was affected by the COVID-19 pandemic, hindering its proper development due to the lack of access to the field, however, although the crops were affected by the restrictions generated by the pandemic there was an increase in production of 87% and 67% respectively in one of the DTU of Pisco and Lambayeque. Table 4 below details the yields for the 2019/2020 season for cotton. In the Justo Córdova DTU, it had a pest attack that resulted in a reduction in productivity of more than 55.7%

Table 4. Yields 2019-2020 Season (QQ/ha)

LOCALITIES	Valle Pisco - Ica		Muy Finca - Lambayeque
DTU	DTU Carmen Mejía	DTU Justo Córdova	DTU Jorge Fuentes
Average cotton Yield	71	31	70.5
Yield in neighboring farms	38	35	45
Yield Increase(%)	87%	-11%	67%

Source: +Cotton Project

Irrigation efficiency

The results involved the identification of critical points to make irrigation decisions and confirming observations of the symptoms of stress and soil pits. This allowed establishing that the critical points of tension for cotton are in a range of 18 and 33 centibars (Table 5).

Table 5. Critical tension according to the phenological stage, to make irrigation decisions

Phenological Stage	**Tension (Centibars)**
Growing	18
Floral bud	25
Flowering	25
Maturation	33
Near to harvest	25

Source: +Cotton Project

Regarding savings in water usage, has been observed that technology has saved 20% of irrigation water, considering a major season (cotton) and a minor season (beans), as can be seen in table 6.

Table 6. Consumption of irrigation water (in m3) in the Water Efficiency Pilot, in the DTU Justo Córdova

Culture	**Time (days)**	**H_20 Used in Pilot**	**H_2O traditional irrigation**	**Saving**	**%**
Cotton	210	8,200	10,000	1,800	18%
Bean	125	3,000	4,000	1,000	25%
TOTAL	335	11,200	14,000	2,800	20%

Source: +Cotton Project

A total of 8 irrigations were carried out within a period of 6 months (October 2018 to April 2019), which, in summary, showed the following information: Total quantity m3/ha of the period 8,270; Total production QQ/ha 88.5; Water used to produce 1 QQ 93.4.

4. Discussion

The use of digital tools in family farming production areas, with technical support, generates positive responses in economic, environmental, and social terms to the extent that it increases crop productivity, and farm yields, optimizes the use of water and soil, and generates digital inclusion processes in the field. The use of Smart Agro 4.0 irrigation technology was shown to increase yields by over 60% in both seasons for cotton and more than 20% for secondary crops. This demonstrates the potential of these technologies in assisting farmers and improving their production systems. Tensiometers in addition to being proven technologies (Hensley & Deputy, 1999) are easy to maintain, install and use tools (Olczyk et al, 2002) and with proven effectiveness in saving water, as demonstrated by Allah and Sholi (2016) where they reduced water use in cucumber crops by 36% by using this technology.

In this sense, digital agriculture technology has the potential to create an agricultural revolution, making crop and livestock production more efficient and more environmentally friendly and contributing to higher productivity. Connectivity, mobile apps, digital platforms, software, global satellite positioning systems, remote sensing, and field sensors are the main technologies used (Naresh et al, 2021). From this, it is possible to open the discussion on the digital impulse for a more sustainable society and economy, involving research in new technologies and the creation of knowledge networks. This is without losing sight of the current scopes and knowledge such as the use of IoT, Big Data, data analytics, and blockchain among others and see how to take advantage of them in the current agricultural context.

As stated by Kolmykova et al (2021), the main arguments in support of the introduction of digital technologies into the agricultural sector are reducing labour intensity and increasing productivity; increasing the efficiency of the resources used; individual approach to keeping and feeding livestock and poultry; an increase in crop quantity and quality; managing the quality of manufactured products; reducing dependence on the human factor; reduction of effects on the environment; updating the technical base of agricultural production.

As a critical point for the execution of this kind of technology can be addressed six considerations for future replication. On a technical level (1) it is necessary to optimize the technical response of the equipment in the field so that irrigation decisions are more effective; (2) consider an adaptation period once the equipment is installed, whose purpose is to define the critical points hand in hand with field technicians; (3) have all the equipment of the solution in the field installed and validated utilizing a descriptive test tube to ensure the obtaining of optimal data and defined critical points. At the operational level it is important to consider the (4) selection of farmers who grow cotton and who are willing to follow the technical indications; (5) identify parcels that have a reservoir or water source that allows them to make irrigation decisions autonomously; (6) having technical assistance in cultivation, which allows them to develop good comprehensive crop management and technical monitoring of the field.

Likewise, it is necessary to continue making efforts to cover the gaps and pending issues such as quality internet access in rural areas, and adequate and enhanced local research and training centers, among others. All this is within a transparent regulatory framework that contemplates the ethical and responsible use of technology.

5. Conclusion

Digital irrigation technologies proved to be an appropriate technology for the efficient use of water and the improvement of cotton crop yields and associates of Peruvian cotton producers in comparison to producers in the vicinity of the DTUs.

The main challenge was the acquisition of new knowledge by the beneficiaries. Another constraint from a future perspective is the monitoring of the crop and irrigation from the software and the generation of recommendations; farmers can manage this technology but require support in precision agriculture tools. In addition, the offer of financing from the State could be added to ensure access to this technology and technical advice, which is essential for its efficient use.

These types of initiatives and analyses such as "Smart Agro" favor the digital transformation process that is so necessary for the agricultural sector, especially in family farming, and revolutionize the efficient use of scarce resources such as water, as well as significantly helping in decision making. These initiatives include IoT solutions to sensor and connect - thus capturing data from any process - and Artificial Intelligence or AI technologies to extract information and knowledge from the data, thus empowering the decision-making capacity of farmers in this case.

The institutional alliance between Telefónica Foundation and FAO contributed to the 2, 6, 11, 12 and 17 Sustainable Development Goals (SDGs) to promote more efficient and effective solutions in the use of natural resources in agriculture. The results are being shared with local governments to help drive these changes from the administrations, where the agri-food issue is becoming increasingly relevant and is one of the priorities on the agendas of Latin American and European countries.

The South-South +Cotton cooperation played a central role in establishing and monitoring the units in the field. It also articulated the participation of the national and departmental government. One of the lessons learned is that it is necessary to expand public-private articulation to generate more sustainable production processes in rural areas.

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