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AGRICULTURE 4.0: DIGITAL TRANSFORMATION IN THE PRODUCTION CHAIN FOR EFFICIENCY AND SUSTAINABILITY IN THE AGRO-INDUSTRIAL SECTOR

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ABSTRACT
The use of high technology in agro-industrial production is a reality in crops, reinforcing the relevance of Agriculture 4.0 as a transforming agent through digitalization and integration of processes. Digital transformation connects all links in the production chain, allowing real-time data from the field to be disseminated and used to improve the control of operations and support strategic decisions with precision. This advancement facilitates more efficient practices, continuous monitoring, and agile responses to environmental and market variables. In this context, this article presents a Systematic Literature Review, addressing the state of the art of Agriculture 4.0, its technologies and practices applied to the agro-industrial sector. In sequence, a case study is applied with data collection in a company that provides technological solutions aimed at the management of the agro-industrial process of the sugar-energy sector. The objective is to analyze and relate the challenges in the integration between the field, technology and the user of the data, in order to identify critical factors that influence the adherence and success of digital solutions. The research seeks to explore how digitalization can optimize operational efficiency, increase productivity, and create opportunities for knowledge management and sustainability in the agribusiness. It was highlighted in the results that the digital transformation in agribusiness, driven by technology 4.0, is changing the way agricultural activities are managed, bringing significant gains in productivity, sustainability and competitiveness, but the growing presence of technologies 4.0 on farms and organizations indicates the importance of a continuous knowledge management plan, which covers both implementation and after-sales monitoring, in order to ensure that users have the skills to deal with innovations. This approach allows not only the technological updating of operations, but also the strengthening of human capital, creating a collaborative environment that is adaptable to changes. It was observed that strengthening the practical knowledge base, with a focus on good practices and use models, is essential for Brazilian agribusiness to make the most of the potential of Agriculture 4.0.

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INTRODUCTION

Digital Agriculture, also known as Agriculture 4.0 (Agro 4.0), has advanced remarkably with technological development and innovations that bring positive and significant impacts to the agro-industrial sector. It is understood that, in addition to producing efficiently, the sector must adopt innovative and sustainable practices, driving the emergence of scalable systems that allow not only increased productivity, but also effective cost control. These systems are capable of storing and processing large volumes of data, interconnecting mobile devices and online platforms to support real-time decision-making (MASSRUHÁ, 2017).

The technological processes used by Agriculture 4.0 contribute to more efficient rural production, that is, increasing productivity, reducing the use of natural resources, such as water, and reducing the use of fertilizers and pesticides, contributing to the reduction of environmental impacts (CLERCQ; VATS; BIEL, 2018). According to Schumpeter (1988), technological innovation is a fundamental force for economic development, made possible by the incorporation of new production techniques, industrial reorganization, and the use of new combinations of productive resources (SEIDLER and FRITZ FILHO, 2016). In this context, the development of smart agriculture becomes essential to achieve the global goals of food security and sustainability, defined by FAO (2010).

Brazil is the world's largest exporter of soybeans, coffee, sugar, orange juice, sugarcane ethanol, beef and chicken. In 2019, agribusiness exports reached US$ 96.8 billion, representing 43.2% of the total exported by the country. Brazilian agriculture is diversified, with more than 300 species cultivated, and exports 350 types of products to 200 markets around the world. Brazil stands out as a major producer of grains, meat, and fruits, and the agricultural sector contributes 21.1% of GDP and employs 20% of the workforce (Embrapa, 2019).

For Silva (2018), Information and Communication Technologies (ICTs) play an auxiliary role in the innovation process by acting as targeted and efficient tools for specific functions. Composed of *hardware* and *software*, these technologies allow the automation of processes such as data collection, transcription, and communication, facilitating interaction between devices and users and integrating information into digital platforms that support agricultural management.

Agriculture 4.0 therefore connects all links in the production chain, promoting the sharing of real data from the field and improving operational control. However, agricultural modernization demands an analysis of technological adoption and diffusion: while adoption represents the individual or organizational decision to incorporate modern technologies, often influenced by microeconomic factors, diffusion is characterized as a more comprehensive process, which evaluates the general and integrated impacts of technology at the strategic, tactical, and operational levels. This distinction is fundamental to understand how different agents – farmers and companies – use these innovations and at what organizational levels they are implemented (MASSRUHÁ, 2017). The success or failure of agricultural technology depends largely on the perception of value and benefits provided by *hardware* and *software* among end users.

The bibliographic review is essential to establish the limits and theoretical foundation of a research, according to the scientific perspective presented by Dane (1990). The author points out that this process involves the definition of key topics, authors, keywords, journals, and preliminary data sources. In this context, the literature review is considered a crucial initial stage for any scientific investigation that, according to Webster and Watson (2002), serves as a foundation for the construction and delimitation of the study.

In view of this scenario, this article carries out a Systematic Bibliographic Review (RBS) of an exploratory nature, bringing together technological solutions highlighted in the literature that dialogue with the context investigated in the case study. This process seeks to provide a critical and structured analysis of the factors that influence the adoption and effectiveness of digital technologies in agribusiness. Based on the data collected, the research explores the panorama of the agro-industrial market and the state of the art on Digital Agriculture, analyzing the connection of these data with knowledge management practices. The case study highlights the importance of data generated by technology 4.0 for agents involved in rural territories, reinforcing the strategic value of this information in the management and operation of the agricultural sector.

LITERATURE REVIEW

The concept of digital agriculture refers to the insertion of information and communication technologies (ICTs), as well as data collection and transmission processes, in agriculture and livestock. Through *hardware* and *software*, this data is converted into strategic tools to increase efficiency, allowing rural producers to reach new levels of productivity and sustainability in the field. Also known as Agriculture 4.0, this approach includes a range of technologies already in operation or under development, such as robotics, nanotechnology, synthetic proteins, cellular agriculture, gene editing, artificial intelligence, *blockchain*, and machine learning, whose transformative effects are expected to shape the future of agriculture and agri-food systems (KLERKXA; ROSEB, 2020).

In the last 30 years, the Brazilian agricultural sector has experienced significant growth, driven by the ability to adapt and improve its cultivation and management techniques, reaching productivity levels similar to those of North America (REVISTA MERCOSUR, 2017). This advance highlights the role of technology as an essential engine for Brazil's global competitiveness in agribusiness. According to Bolfe and Massruhá (2020), digital transformation in Brazilian rural properties is no longer an option, but a vital need to increase competitiveness and value integration throughout the production chain. Agriculture 4.0, therefore, not only modernizes the sector, but also enables a vision of the future where innovation and technology improve the sustainability and efficiency of agri-food systems.

INFORMATION AND COMMUNICATION TECHNOLOGY (ICT)

In agriculture, Information and Communication Technologies (ICTs) emerge as innovation opportunities to face challenges such as increasing productivity without expanding the planted area and, especially, to improve the management of data, information and knowledge throughout the production chain (MASSRUHÁ, 2017). In the agro-industrial sector, the adoption of ICTs creates an environment rich in possibilities to reduce informational asymmetry. The role of technology, therefore, is not to centralize knowledge, but to apply it in a way that contributes to the generation of new knowledge and innovations (CASTELLS, 1999).

Digital agriculture in rural areas encompasses the generation and processing of large volumes of digital data, which has the potential to drive innovation at all stages of production, including pre-production, production, and post-production (BOLFE et al., 2021). In Figure 1, Massruhá et al. (2020) present a detailed overview of this digital transformation scenario, showing how ICTs permeate the agricultural production chain.

Figure 1 presents a structured view of digital agriculture along three stages of the production chain: pre-production, production, and post-production. In each of these

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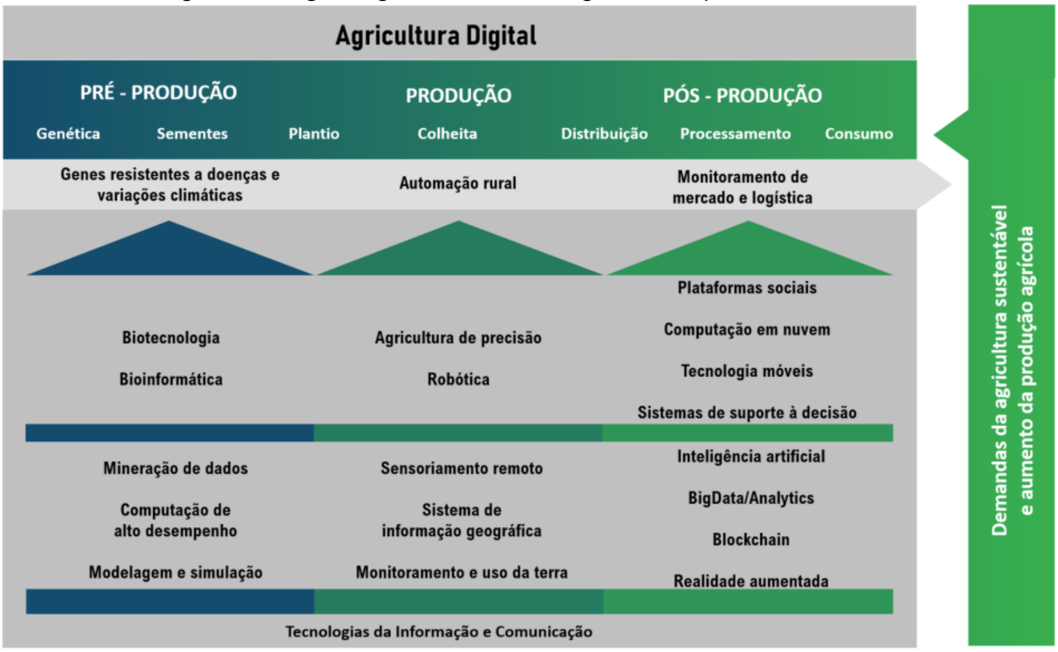
phases, technologies such as biotechnology, precision agriculture, and artificial intelligence are applied to improve the efficiency and sustainability of production. Pre-production focuses on genetics and disease resistance; the production emphasizes rural automation and remote sensing; while post-production uses logistical monitoring and social platforms. This set of innovations meets the demands for a more sustainable agriculture with greater productive capacity.

Figure 1 - Digital agriculture in the agricultural production chain



Source: Masshurá *et al.* (2020)

INTERNET OF THINGS (IOT)

According to Lee and Lee (2015), the Internet of Things (IoT) is an innovative technological trend that encompasses a network of machines and devices capable of interacting autonomously. In the context of automation, IoT collects data through sensors, processes this information with controllers, and completes the automation process through actuators, allowing for greater precision and efficiency in operations. Triantafyllou et al. (2019) highlight that smart farming is based on the integration of modern technologies, such as IoT and Cloud Computing, in a cyber-physical field management cycle. These technologies accelerate the digital transformation of traditional agricultural practices, promoting an increase in productivity and improvement in the quality of agricultural products.

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Atzori, Iera, and Marobito (2010) complement the concept of IoT by stating that the various devices that surround us – including sensors, *smartphones*, actuators, and electronic identifiers – can interact and cooperate with each other through integrated communication and addressing schemes, with the aim of achieving a common purpose, such as precise monitoring and automated control. In the Brazilian context, the expansion of connectivity in rural areas, associated with the integration of sensory systems, remote sensors, agricultural equipment and mobile devices, has driven the adoption of digital agriculture. In Chart 1, Bolfe et al. (2020) present a survey carried out with 504 Brazilian farmers, which lists the digital technologies in use and the respective implementation complexities.

Frame 1 - Digital agriculture technologies

Tecnologias	**Complexidade das Aplicações**
Internet e Conectividade/*Wireless*	Baixa
Aplicativos Móveis, Plataformas Digitais e *Software*	
Sistemas de Posicionamento Global (GPS)	
Mapas Digitais	
Sensores de Proximidade e de Campo	Média
Sensores Remotos	
Eletrônica embarcada, telemetria e automação	
Deep Machine Learning e Internet das Coisas	Alta
Computação em Nuvem, *Big Data, Blockchain* e Criptografia	
Inteligência Artificial	

Source: Bolfe et al. (2020)

The case study presented in this article incorporates, in its application technology, the three layers of complexity, contemplating the low, medium and high classifications, in order to provide a comprehensive analysis of the different scales of implementation and their impacts on the effectiveness and performance of the system in different scenarios.

Graph 1, also mentioned by Bolfe et al. (2020), allows us to visualize the technologies currently employed by these farmers.

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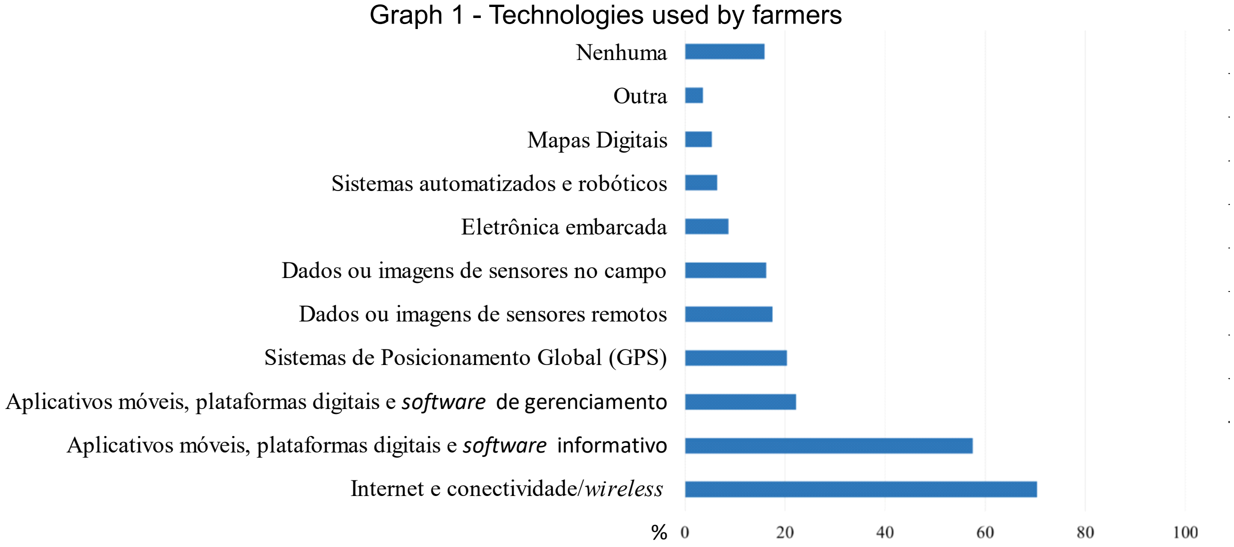
Graph 1 - Technologies used by farmers



Source: Bolfe et al. (2020)

ORGANIZATIONAL PLANNING

According to Kotler (2020), strategic planning is the process of developing an action plan for each business area, with the aim of achieving long-term goals, taking into account the company's position in the sector and taking advantage of its capabilities and resources. In the context of agribusiness, strategic planning focuses on the search for competitive advantage, with an emphasis on efficient and sustainable agricultural practices, aiming to maximize profits while minimizing operating costs. Detailed planning is essential to guide the organization in the sector, understand its current situation, and draw projections for future investments.

In this scenario, when planning the technological upgrade, it is crucial to identify the best service and platform options available in the market. This process must consider the impacts and reflections on stakeholders, the learning time required, and finally, the quality of the information generated, ensuring a positive return on investment. For Heleno (2009), the lack of application of management techniques in Brazil, especially in the agricultural sector, results in significant losses for national agribusiness, including the absence of Rural Business Plans. The strategy adopted by an organization is decisive for its success or failure.

To understand the concept of strategic planning, it is necessary to address general planning, which is divided into three levels, according to Daft apud Fernandes (2022):

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- Operational planning: short-term, focused on daily operations, being the responsibility of lower-level managers.
- Tactical planning: medium-term, focused on the company's sectors or divisions, responsibility of executives and managers.
- Strategic planning: long-term, which involves top management and deals with the organization as a whole.

This article discusses, through a case study, the impacts of the tactical and operational divisions in an industry in the sugar-energy sector. Analysis of these layers is essential because of the significant effects on the learning curve and data generation within the organization.

METHODOLOGY

The research had an exploratory character, starting with a bibliographic review on the state of the art of the theme in question, followed by a case study. The data collection was carried out in a company specialized in providing technological solutions aimed at the management of the agro-industrial process in mills in the sugar-energy sector.

This approach allowed a detailed analysis of the practices and challenges faced by companies in the sector, in addition to enabling the identification of trends and technological innovations that impact the operational efficiency and sustainability of the plants.

SYSTEMATIC LITERATURE REVIEW (RBS)

The method adopted was the Systematic Literature Review (RBS), as defined by Conforto (2011). This methodological approach aims to carry out a critical and in-depth analysis of the existing literature on a specific topic, following a rigorous and structured process. The main objective of RBS is to gather, analyze and synthesize the evidence already produced on the subject, identifying patterns, gaps and trends in the literature.

The search covered a period of five years, using the Scopus database to search for articles published between 2017 and 2022 in scientific journals. The following keywords were used for the bibliographic analysis, present in the title, abstract or keywords: "*digital agriculture*", "*technology application*" and "*farming*". For the initial analysis, a minimum of 15 citations was adopted as a qualification criterion. After applying this filter, 29 articles were selected, which allowed focusing on the most relevant and impactful publications within the theme, ensuring the quality of the subsequent analysis. This careful selection contributed to a more accurate view of the trends and significant contributions in the field of digital technologies in agribusiness. In the next stage, the abstracts of all 29 articles listed were read. From this analysis, 10 articles were selected for a more detailed evaluation, based on their relevance and depth. These articles served as a foundation for the construction of the theoretical framework of this case study, ensuring a solid and updated basis on the subject and conferring consistency and robustness to the research.

APPLICATION TO THE CASE STUDY

This topic presents a case study, in which digital data from an agroindustry focused on the cultivation of sugarcane are analyzed. The study follows the project timeline, offering a detailed analysis of both the technology implementation period and the two years following the digital transformation.

The company providing the technology

Fully adapted to the reality of the field, the company stood out when it was born with the mission of improving the efficiency of the sugar-energy sector, a market that faces the constant need for innovation and reinvention every year, aiming to ensure its competitiveness in the global market, improve the efficiency of its production and meet new demands and environmental and economic challenges. The company's first office was opened in Araçatuba, in the interior of São Paulo, and currently serves as its headquarters. With exponential growth, the company consolidated its global representation in Artificial Intelligence (AI) and Software as a Service (SaaS) for agribusiness, offering technologies that integrate monitoring, productivity, traceability, and logistics. Its expansion was rapid and global, currently managing more than 9 million hectares in real time, in Brazil, the United States, Canada and several Latin American countries. In all, the company is present in more than 11 countries around the world, the company has about 850 employees.

Among the products offered to global agribusiness are on-board computers, telemetry systems, *software* for managing and controlling mobile assets, applications and specialized sensors, among others. The commercialization rates are impressive, with more than 3.7 trillion data collected annually, 6 thousand transactions carried out per second and estimates of return to the producer of up to 30% gain in productivity and efficiency.

These innovations not only optimize the management process but also drive sustainability and competitiveness in the global agricultural sector.

The company that invested and implemented the digital solutions in its agro-industrial process

The company has two industrial units in the interior of São Paulo, which, together, have the capacity to process 6.4 million tons of sugarcane per harvest. These units operate with about 420 active agricultural equipment in their machinery park, generating more than 2.6 thousand jobs in the agricultural, industrial and administrative areas. In this article, it was decided to extract data from the unit with the greatest representativeness for the company, which has approximately 263 agricultural machines in operation. This choice aims to provide a more in-depth analysis of the operations and impacts of the technology implemented in the larger unit.

IMPLEMENTED TECHNOLOGY

The proposed solution uses operational information generated in real time by the equipment, ensuring the reliability of the records and requiring minimal operational intervention during the execution of the processes. Through an integrated system of *hardware* and *software*, the solution offers the following benefits: Increased data reliability; Reduction of human intervention; Decision-making based on accurate data; Real-time monitoring of the equipment fleet of the harvesting front; Optimization of available resources.

The project incorporated automation and telemetry solutions, with the installation of on-board computers to capture and generate information from the operations carried out. This information is transmitted through the GPRS (*General Packet Radio Service*) network and processed in the company's database, allowing continuous monitoring of the fleet, the monitoring of productive and unproductive operations, and the issuance of various management and operational reports, accessible through an *online* platform and cloud data storage.

Automated Pointing (State Machine)

With the intelligence incorporated into the on-board computers and through the logic of analog and digital signals captured by the equipment, it is possible to automatically identify the operational states (effective, maneuver, displacement), without the need for human intervention during the operation cycle. However, it is necessary to record the reasons for the stoppages, such as maintenance, rain, meal, among others.

The on-board computer has an on-board software that offers dynamic and clear pointing options, allowing the operator to perform simple and efficient interventions to record operations typically classified as unproductive, which require manual intervention.

Automated Process Management System (LMS)

The on-board computers enable the georeferenced identification of the equipment, recording its operations according to the defined parameterization, including categories such as productive, unproductive, auxiliary, maintenance and climatic. This information is stored on a memory card embedded in the *hardware* and sent to the monitoring system via GPRS.

The Automated Process Management System (SGPA) is the *software* responsible for receiving, processing and visualizing the data sent by the on-board computers installed in the equipment. This system allows the spatial visualization (on georeferenced maps) of the positioning of the equipment, along with its operational status, operator data and alerts. The transmission of data may vary according to the conditions of the GPRS network, and it is possible to generate *offline* reports, i.e. post-processing of the data.

Agricultural Operations Center (AOC)

The objective of the COA is to provide greater reliability in the analysis of customer data, ensuring the effective use of this information to maximize efficiency and reduce costs. The COA acts as a strategic sector within the business, identifying and acting quickly in situations that impact operational performance, in addition to analyzing and solving the main bottlenecks in real time. To achieve near-optimal routing, the COA should apply:

- Premises: Availability of resources for analysis, commitment of the project sponsors, effectiveness in the proposed activities and continuous monitoring.
- Restrictions: Training of operators and leaders of the cutting fronts, with the objective of forming analytical teams within the COA.

In section 2.3, the subdivisions of organizational planning are presented, as the concept of tactical implementation is directly connected with the strategic routine

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integrated in the activities of the Agricultural Operations Center. In this context, it is observed that the COA is the main recipient of information, offering a holistic view of each operation and connecting, at all times, business strategies to management. This integration makes the COA a key point of the operational gear in the agricultural environment. The main objective of this area is to ensure the maximum efficiency of agricultural assets, increasing the productivity of machines and, consequently, reducing operating costs.

THE IMPLEMENTATION OF THE PROJECT

In the 2019 harvest, an agreement was signed between the contractor and the contractor to develop a master plan for technological implementation, with the objective of serving the machinery park of the sugar-energy plant discussed in this article. The scope of the project included the creation of an operation that would cover the entire structure necessary for the technological insertion of the 263 agricultural equipment available, including an online monitoring solution with automated notes (machine status) and the management platform website of the Automated Process Management System (SGPA), in addition to the creation of the client's Agricultural Operations Center.

To ensure the successful implementation of the proposed solutions, it was essential to maintain high-performing teams, with specialized technical knowledge, project management skills, and well-defined flows by the Project Management Office (PE). The integration of the initiation, planning, execution, control and closure processes was essential to ensure the quality of the services provided.

The initial schedule estimated a total of 488 hours of effort, starting on 10/14/2019 and ending on 12/19/2019. However, due to adversities encountered during the deployment, the actual effort was 566 hours, exceeding the initial estimate. Even with this increase in hours, the project was completed on time. The activities foreseen in the project implementation plan are presented below.

Frame 2 - Detailed implementation schedule; *Software* Ms Project®

Task Name	Work	Beginning	End
CASE STUDY PROJECT	488 hrs	Mon 14/10/19	Tue 24/12/19
100 - Initiation	8 hrs	Mon 14/10/19	Fri 18/10/19
Document required for project definition	8 hrs	Mon 14/10/19	Mon 14/10/19

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200 - Planning	16 hrs	Tue 15/10/19	Thu 17/10/19
Customer Visit	8 hrs	Tue 15/10/19	Tue 15/10/19
Request list of documents required for integration	0 hrs	Tue 15/10/19	Tue 15/10/19
Request - Parameterization Worksheet	1 hr	Wed 16/10/19	Wed 16/10/19
Validate - Responsibility Matrix	1 hr	Wed 16/10/19	Wed 16/10/19
Validate - Delivery Plan	1 hr	Wed 16/10/19	Wed 16/10/19
Validate - Communication Plan	1 hr	Wed 16/10/19	Wed 16/10/19
Validate - Timeline	3 hrs	Wed 16/10/19	Wed 16/10/19
Submit Firmware Request	1 hr	Thu 17/10/19	Thu 17/10/19
300 - Executing and controlling	436 hrs	Mon 21/10/19	Mon 16/12/19
KICK OFF MEETING	8 hrs	Mon 21/10/19	Mon 21/10/19
Prepare Formatters of Card and Folder Records - CCT	56 hrs	Thu 24/10/19	Fri 01/11/19
Prepare Formatters for Card and Folder Records - TPL	80 hrs	Mon 04/11/19	Fri 15/11/19
Integration	8 hrs	Tue 22/10/19	Tue 22/10/19
Prepare and submit documentation	4 hrs	Tue 22/10/19	Tue 22/10/19
Perform onboarding process	4 hrs	Tue 22/10/19	Tue 22/10/19
Deliveries and installations	0 hrs	Mon 21/10/19	Fri 13/12/19
Delivery of Installation Kits	0 hrs	Mon 21/10/19	Fri 29/11/19
Delivery of materials (Harvester Kits)	0 hrs	Mon 21/10/19	Mon 21/10/19
Delivery of materials (Transshipment Kits)	0 hrs	Mon 21/10/19	Mon 21/10/19
Delivery of materials (Sugarcane Kits)	0 hrs	Mon 21/10/19	Mon 21/10/19
Delivery of materials (TPL Kits)	0 hrs	Mon 21/10/19	Mon 21/10/19
Facilities	0 hrs	Tue 22/10/19	Fri 13/12/19
Validate Installation (F5/F4/F3/F2/F1 Harvesters)	0 hrs	Fri 08/11/19	Fri 08/11/19
Validate installation (F5/F4/F3/F2/F1 overflows)	0 hrs	Fri 08/11/19	Fri 08/11/19
Validate installation (Canavieiros)	0 hrs	Fri 15/11/19	Fri 15/11/19
Validate Installation (TPL)	0 hrs	Fri 13/12/19	Fri 13/12/19
Training	8 hrs	Wed 23/10/19	Wed 23/10/19
Conduct training for technicians and multipliers	8 hrs	Wed 23/10/19	Wed 23/10/19

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SGPA	4 hrs	Mon 28/10/19	Wed 13/11/19
Sending information for the preparation of the Environment	4 hrs	Tue 22/10/19	Tue 22/10/19
Validate startup from the SGPA environment	0 hrs	Mon 11/11/19	Mon 11/11/19
Validate SGPA Training	0 hrs	Wed 13/11/19	Wed 13/11/19
Start-UP	272 hrs	Mon 11/11/19	Mon 16/12/19
Go-Live Online Monitoring - CCT	36 hrs	Mon 11/11/19	Fri 29/11/19
Start-UP, Train and Instruct Operation - F5	24 hrs	Mon 11/11/19	Wed 13/11/19
Assisted Monitoring and Validation	8 hrs	Thu 14/11/19	Thu 14/11/19
Validate - Mo.	4 hrs	Fri 15/11/19	Fri 15/11/19
Front 4 and 3 Validation	36 hrs	Mon 18/11/19	Fri 22/11/19
Start-UP, Train and Instruct Operation - Online Monitoring	24 hrs	Mon 18/11/19	Wed 20/11/19
Assisted Monitoring and Validation	8 hrs	Thu 21/11/19	Thu 21/11/19
Validate - Mo.	4 hrs	Fri 22/11/19	Fri 22/11/19
Front 2 and 1 Validation	36 hrs	Mon 25/11/19	Fri 29/11/19
Start-UP, train and instruct operation - Mo.	24 hrs	Mon 25/11/19	Wed 27/11/19
Follow-up Mo.	8 hrs	Thu 28/11/19	Thu 28/11/19
Validate - Mo.	4 hrs	Fri 29/11/19	Fri 29/11/19
Go-Live Online Monitoring - TPL	164 hrs	Mon 18/11/19	Mon 16/12/19
Start-UP, train and instruct operation - Mo. TPL	120 hrs	Mon 18/11/19	Fri 06/12/19
Follow-up Mo. TPL	40 hrs	Mon 09/12/19	Fri 13/12/19
Validate - Mo. TPL	4 hrs	Mon 16/12/19	Mon 16/12/19
400 - Closing Phase	28 hrs	Wed 18/12/19	Thu 19/12/19
Closing Meeting	12 hrs	Wed 18/12/19	Wed 18/12/19
Delivery of the Term of Acceptance	0 hrs	Wed 18/12/19	Wed 18/12/19
Lessons learned report	16 hrs	Thu 19/12/19	Thu 19/12/19

Source: The Authors. Adapted from Ms Project®

In the schedule of activities, it is observed that a large part of the efforts was dedicated to training and work instructions for the operational and tactical teams involved in the process. This is due to the fact that the success of the project depends directly on

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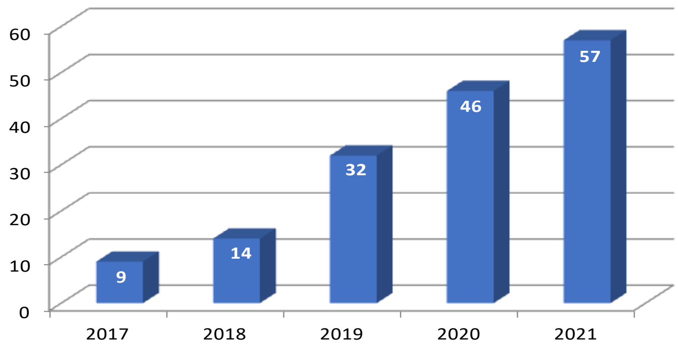
the engagement and knowledge of these two layers, which are fundamental for the effective execution of the strategy and the implementation of the proposed technological solutions.

RESULTS

DETAILED ANALYSIS OF THE SYSTEMATIC LITERATURE REVIEW (RBS)

Throughout the period analyzed in this research, 158 articles were published, as illustrated in Graph 2, which presents the annual evolution of publications. This analysis made it possible to identify the main trends and innovations in the application of digital technologies in the agricultural sector, as well as to provide an overview of the pace of academic production and the areas of greatest research focus within digital agriculture.

Graph 2 - Evolution of publications related to keywords



Source: Scopus (2022)

There is a growing production of works on the researched topic, reflecting the growing relevance of the use of digital technologies in agribusiness. In fact, researchers from different parts of the world have shared their experiences and advances in this field. Graph 3 illustrates the origin of the countries responsible for the publications, with India leading the list, with a share of 22.8%. Brazil occupies the seventh position, with 4.4% of publications, tied with the United States and ahead of China. This panorama highlights India's global role and the growing contribution of Brazil and other nations to the advancement of digital technologies in the agricultural sector.

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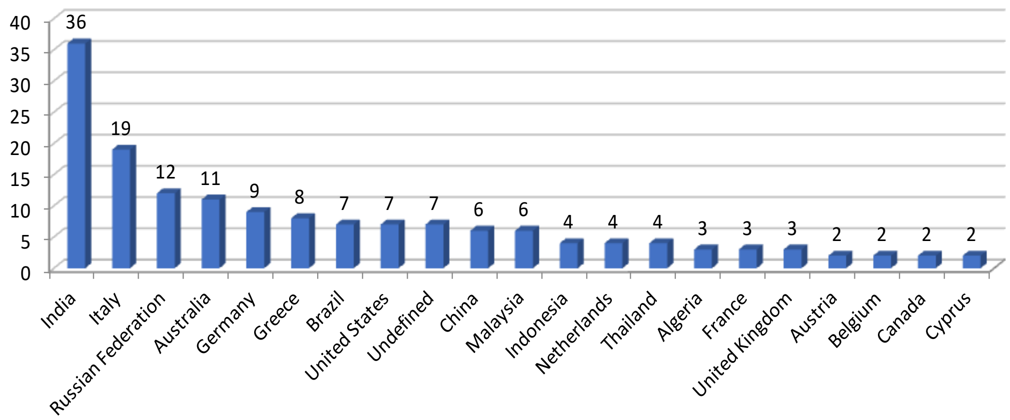
Graph 3 - Countries of origin of the posts related to the keywords



Source: Scopus (2022)

The method of selecting articles, based on keyword filters such as "*digital agriculture*", "*technology application*" and "*farming*", resulted in the choice of 29 articles that highlight the most impactful and relevant research on digital technologies in agribusiness. This thoughtful approach has made it possible to accurately identify key trends and innovations, as well as highlight the field's significant contributions. In Tables 2 and 3, it is possible to view the selected articles, with each position categorized according to the number of citations, offering a consolidated view of the academic relevance of each study.

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Frame 3 - Qualified articles with a minimum of 15 citations

Pos.	Título	Autores	Ano de publicação	Revista	Citações
1	A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming	Farooq, M.S., Riaz, S., Abid, A., Abid, K., Naeem, M.A.	2019	IEEE Access 7,8883163, pp. 156237-156271, 96(4), pp. 1540-1550, 293,126130	181
2	Managing Socio-Ethical Challenges in the Development of Smart Farming: From a Fragmented to a Comprehensive Approach for Responsible Research and Innovation	Eastwood, C., Klerkx, L., Ayre, M., Dela Rue, B.	2019	Journal of Agricultural and Environmental Ethics, 32(5-6), pp. 741-768, 4(2),8620543, pp. 1085-1092	96
3	"If they don't tell us what they do with it, why would we trust them?" Trust, transparency and benefit-sharing in Smart Farming	Jakku, E., Taylor, B., Fleming, A., (...), Sounness, C., Thorburn, P.	2019	NJAS - Wageningen Journal of Life Sciences, 90-91,100285, 340, pp. 234-248	89
4	Applications of remote sensing in precision agriculture: A review	Sishodia, R.P., Ray, R.L., Singh, S.K.	2020	Remote Sensing, 12(19), 3136, pp. 1-31, 350(1),012074	66
5	Plant phenotyping research trends, a science mapping approach	Costa, C., Schurr, U., Loreto, F., Menesatti, P., Carpentier, S.	2019	Frontiers in Plant Science, 9,1933	56
6	Adoption of the Internet of Things (IoT) in agriculture and smart farming towards urban greening: A review	Madushanki, A.A.R., Halgamuge, M.N., Wirasagoda, W.A.H.S., Syed, A.	2019	International Journal of Advanced Computer Science and Applications, 10(4), pp. 11-28	54
7	Spaceborne Imaging Spectroscopy for Sustainable Agriculture: Contributions and Challenges	Hank, T.B., Berger, K., Bach, H., (...), Zarco-Tejada, P., Mauser, W.,	2019	Surveys in Geophysics, 40(3), pp. 515-551	50
8	A smart decision system for digital farming	Baseca, C.C., Sendra, S., Lloret, J., Tomas, J.	2019	Agronomy, 9(5), 216	49
9	Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe	Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., Borges, F.	2020	Precision Agriculture, 21(1), pp. 34-50	43
10	Development and evaluation of drone mounted sprayer for pesticide applications to crops	Yallappa, D., Veerangouda, M., Maski, D., Palled, V., Bheemanna, M.	2017	GHTC 2017 - IEEE Global Humanitarian Technology Conference, Proceedings, 2017-January, pp. 1-7	39
11	Machine Learning Applications for Precision Agriculture: A Comprehensive Review	Sharma, A., Jain, A., Gupta, P., Chowdary, V.	2021	IEEE Access, 9,9311735, pp. 4843-4873	38
12	Agro-tech: A digital model for monitoring soil and crops using internet of things (IOT)	Pandithurai, O., Aishwarya, S., Aparna, B., Kavitha, K.	2017	ICONSTEM 2017 - Proceedings: 3rd IEEE International Conference on Science Technology, Engineering and Management, 2018-January, pp. 342-346	36
13	Precision agriculture: A remote sensing monitoring system architecture	Triantafyllou, A., Sarigiannidis, P., Bibi, S.	2019	Information (Switzerland), 10(11),348	32
14	A survey on LoRa for IoT: Integrating edge computing	Sarker, V.K., Queralta, J.P., Gia, T.N., Tenhunen, H., Westerlund, T.	2019	2019 4th International Conference on Fog and Mobile Edge Computing, FMEC 2019, 8795313, pp. 295-300	31
15	IoT Solutions for Precision Farming and Food Manufacturing: Artificial Intelligence Applications in Digital Food	Dolci, R.	2017	Proceedings - International Computer Software and Applications Conference, 2,8029960, pp. 384-385	30
16	Smart farming technology innovations – Insights and reflections from the German Smart-AKIS hub	Knierim, A., Kernecker, M., Erdle, K., (...), Borges, F., Wurbs, A.	2019	NJAS - Wageningen Journal of Life Sciences, 90-91,100314	28
17	New directions for integrated weed management: Modern technologies, tools and knowledge discovery	Korres, N.E., Burgos, N.R., Travlos, I., (...), Rouse, C.E., Salas-Perez, R.	2019	Advances in Agronomy, 155, pp. 243-319	28
18	Farming smarter with big data: Insights from the case of Australia's national dairy herd milk recording scheme	Newton, J.E., Nettle, R., Pryce, J.E.	2020	Agricultural Systems, 181,102811	23
19	Smart agriculture – Urgent need of the day in developing countries	Goel, R.K., Yadav, C.S., Vishnoi, S., Rastogi, R.	2021	Sustainable Computing: Informatics and Systems, 30,100512	21
20	Precision agriculture as a driver for sustainable farming systems: State of art in litterature and research	Bucci, G., Bentivoglio, D., Finco, A.	2018	Quality - Access to Success, 19(S1), pp. 114-121	21
21	An operational workflow to assess rice nutritional status based on satellite imagery and smartphone apps	Nutini, F., Confalonieri, R., Crema, A., (...), Stavrakoudis, D., Boschetti, M.	2018	Computers and Electronics in Agriculture, 154, pp. 80-92	20
22	Precision and digital agriculture: Adoption of technologies and perception of Brazilian farmers	Bolfe, É.L., Jorge, L.A.C., Sanches, I.D., (...), Ferreira, V.R., Ramirez, A.R.	2020	Agriculture (Switzerland), 10(12),653, pp. 1-16	19
23	May smart technologies reduce the environmental impact of nitrogen fertilization? A case study for paddy rice	Bacenetti, J., Paleari, L., Tartarini, S., (...), Amicizia, F., Confalonieri, R.	2020	Science of the Total Environment, 715,136956	18
24	UAV application for precision agriculture	Perz, R., Wronowski, K.	2019	Aircraft Engineering and Aerospace Technology, 91(2), pp. 257-263	17
25	An architecture model for smart farming	Triantafyllou, A., Tsouros, D.C., Sarigiannidis, P., Bibi, S.	2019	Proceedings - 15th Annual International Conference on Distributed Computing in Sensor Systems, DCOSS 2019 8804834, pp. 385-392	16

Source: Scopus (2022)

Frame 4 - Continuation of qualified articles with a minimum of 15 citations

Pos.	Título	Autores	Ano de publicação	Revista	Citações
26	Putting agricultural equipment and digital technologies at the cutting edge of agroecology	Bellon-Maurel, V., Huyghe, C.	2017	OCL - Oilseeds and fats, Crops and Lipids, 24(3),D307	16
27	Reduction of fertilizer use in South China-Impacts and implications on smallholder rice farmers	Wehmeyer, H., de Guia, A.H., Connor, M.	2020	Sustainability (Switzerland), 12(6),2240	15
28	Anaerobic digestion, solid-liquid separation, and drying of dairy manure: Measuring constituents and modeling emission	Aguirre-Villegas, H.A., Larson, R.A., Sharara, M.A.	2019	Science of the Total Environment, 696,134059	15
29	A framework of cybersecurity approaches in precision agriculture	Chi, H., Welch, S., Vasserman, E., Kalaimannan, E.	2017	Proceedings of the 12th International Conference on Cyber Warfare and Security, ICCWS 2017, pp. 90-95	15

Source: Scopus (2022)

Among the 10 articles selected for more detailed evaluation, key concepts were extracted that enrich the theoretical framework of the research. The following is a concise summary of the main themes covered in the most relevant articles.

- *A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming:* The Internet of Things (*IoT*) is an innovative technology that offers efficient solutions to modernize various areas, including agriculture. The article covers the main aspects of *IoT technologies* applied to agriculture, explaining their components and discussing the network technologies used, such as architecture, layers, topologies, and protocols. In addition, it explores the integration of *agricultural IoT* systems with cloud computing, storage, and big data analytics. The text also highlights safety issues and presents *smartphone* and sensor applications for agricultural management. International regulations and success stories are also addressed, along with research challenges in the field of *IoT agriculture*.

- *Applications of remote sensing in precision agriculture: A review: Agriculture* plays a crucial role in meeting basic human needs, but faces challenges due to increased demand for food, population growth, and environmental impacts. Emerging technologies such as *IoT*, *Big Data* analytics , and artificial intelligence are being utilized to make more informed decisions and increase agricultural production sustainably. Precision agriculture (PA) applies these technologies to optimize the use of inputs and reduce waste. The use of remote sensing, such as satellite imagery and unmanned aerial vehicles (*UAVs*), has increased in recent decades, allowing for accurate crop monitoring and resource management. The adoption of these technologies depends on the development of efficient and easy-to-use systems, favoring their large-scale application in commercial agriculture.
- *Adoption of the Internet of Things (IoT) in agriculture and smart farming towards urban greening: A review:* This study analyzes the application of the Internet of Things (*IoT*) in the agricultural and livestock industries, highlighting how it can improve productivity and reduce human intervention through automation. The research, based on 60 scientific publications from 2016 to 2018, focuses on IoT subverticals such as water management (28.08%), crop management (14.60%) and smart agriculture (10.11%). Data collection covers measurements such as ambient temperature, moisture, and soil pH. Wi-Fi is the most used technology (30.27%), followed by mobile technology (21.10%). The results indicate that the agricultural sector is more researched (76.1%) than the agricultural sector (23.8%). The study offers recommendations for future research, including the scalability of *IoT systems*, security and cloud platforms, with a focus on improving the efficiency of agricultural production.
- *Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe:* Technological innovations, especially so-called smart farming technologies (*SFTs*), are transforming mechanization in agriculture and promoting more sustainable agriculture in Europe. A survey of 287 farmers from seven EU countries and 22 experts

revealed that 50% of farmers have adopted *SFTs*, with greater adoption on larger farms and in arable cropping systems. While farmers recognize the usefulness of *SFTs*, many have doubts about their potential in farm-specific challenges. In addition, both adopters and non-adopters have hesitations, the former are disillusioned with the technologies they use, while the latter question their availability and accessibility. The survey indicated that 60% of farmers suggest improvements to make *SFT* more relevant. Peer-to-peer communication is seen as an important source of information, and both farmers and experts highlight the need for unbiased advice. Experts generally have a more positive view on *SFT* and its long-term trends. The results suggest that in order to improve the adoption and development of *SFTs*, it is necessary to consider the differences in Europe's agricultural structures and cropping systems.

- *Precision and digital agriculture: Adoption of technologies and perception of Brazilian farmers:* Rapid population growth has increased the demand for food, fiber, energy and water, requiring the most sustainable use of natural resources. Since the 1990s, precision agriculture has promoted productive gains and greater efficiency in the use of inputs. Rural connectivity and integration with data from sensors and mobile devices have given rise to Agriculture 4.0 or digital. A survey of 504 Brazilian farmers revealed that 84% use at least one digital technology in their operations, with benefits perceived mainly in increased productivity. Challenges include the costs of acquiring technologies and connectivity. In addition, 95% of farmers showed interest in learning about new technologies to improve their properties.

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Chart 4 presents the 10 selected articles that were used as a basis for the construction of the theoretical framework of this study.

Frame 5 - Articles for theoretical framework

1	A Survey on the Role of IoT in Agriculture for the Implementation of Smart Farming	Farooq, M.S., Riaz, S., Abid, A., Abid, K., Naeem, M.A.	2019	IEEE Access 7,8883163, pp. 156237-156271, 96(4), pp. 1540-1550, 293,126130	181
4	Applications of remote sensing in precision agriculture: A review	Sishodia, R.P., Ray, R.L., Singh, S.K.	2020	Remote Sensing, 12(19), 3136, pp. 1-31, 350(1),012074	66
6	Adoption of the Internet of Things (IoT) in agriculture and smart farming towards urban greening: A review	Madushanki, A.A.R., Halgamuge, M.N., Wirasagoda, W.A.H.S., Syed, A.	2019	International Journal of Advanced Computer Science and Applications, 10(4), pp. 11-28	54
9	Experience versus expectation: farmers' perceptions of smart farming technologies for cropping systems across Europe	Kernecker, M., Knierim, A., Wurbs, A., Kraus, T., Borges, F.	2020	Precision Agriculture, 21(1), pp. 34-50	43
13	Precision agriculture: A remote sensing monitoring system architecture	Triantafyllou, A., Sarigiannidis, P., Bibi, S.	2019	Information (Switzerland), 10(11),348	32
14	A survey on LoRa for IoT: Integrating edge computing	Sarker, V.K., Queralta, J.P., Gia, T.N., Tenhunen, H., Westerlund, T.	2019	2019 4th International Conference on Fog and Mobile Edge Computing, FMEC 2019, 8795313, pp. 295-300	31
22	Precision and digital agriculture: Adoption of technologies and perception of Brazilian farmers	Bolfe, É.L., Jorge, L.A.C., Sanches, I.D., (...), Ferreira, V.R., Ramirez, A.R.	2020	Agriculture (Switzerland), 10(12),653, pp. 1-16	19
25	An architecture model for smart farming	Triantafyllou, A., Tsouros, D.C., Sarigiannidis, P., Bibi, S.	2019	Proceedings - 15th Annual International Conference on Distributed Computing in Sensor Systems, DCOSS 2019 8804834, pp. 385-392	16
26	Putting agricultural equipment and digital technologies at the cutting edge of agroecology	Bellon-Maurel, V., Huyghe, C.	2017	OCL - Oilseeds and fats, Crops and Lipids, 24(3),D307	16
29	A framework of cybersecurity approaches in precision agriculture	Chi, H., Welch, S., Vasserman, E., Kalaimannan, E.	2017	Proceedings of the 12th International Conference on Cyber Warfare and Security, ICCWS 2017, pp. 90-95	15

Source: Scopus (2022)

DETAILED CASE STUDY ANALYSIS

This article focuses on the analysis of the results obtained during the year of implementation of the technological solution and, subsequently, after two years of its use, with a specific monitoring of the process of cutting and loading the raw material.

The analysis focuses on the data generated by harvesters and transshipment tractors, equipment sized within the scope of the project.

The first survey carried out involved an analysis of the historical basis of the data collected by the on-board computers installed in the organization's harvesting equipment. This data served as the analytical basis for the case study.

The work fronts are illustrated in graph 4, which presents the sizing of the equipment used in the 2019, 2020 and 2021 harvests, with a specific focus on the month of October of each year.

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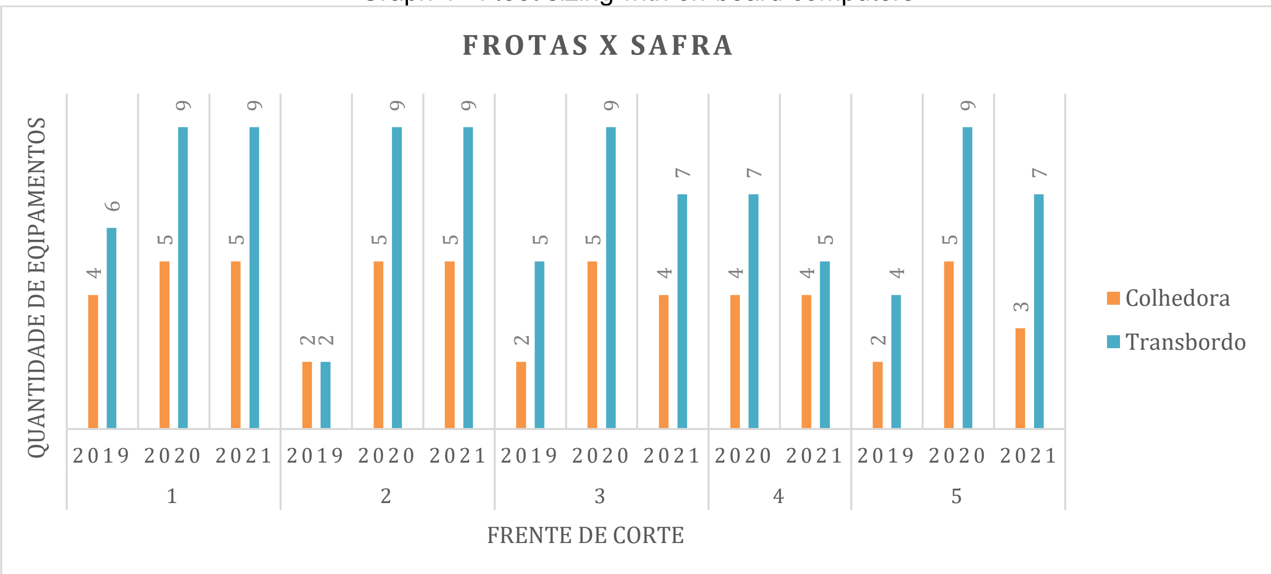
Graph 4 - Fleet sizing with on-board computers



Source: The Authors.

The second topic analyzed refers to the occurrence rates, presented in hours, generated by the operation called "No Point". This operation is characterized by the only demand for man/machine intervention, occurring when the operator, through the on-board computer, fails to record the equipment downtime, automatically resulting in an unproductive operation "No Pointing".

To apply the concept of COA, as presented in section 3.3.3, it is essential that the tactical team performs a continuous and assertive monitoring of operational *performance*, with a focus on improving the quality of information.

In this context, mapping production stoppages allows the registration of unproductive operations, facilitating the control and comparison between what was planned and what was accomplished, as defined by the Agricultural Operations Center.

High "No Pointing" rates make the process imprecise, generate distortions in management results and hinder continuous improvement actions, which aim to transform the opportunities identified in unproductive operations into efficiency gains in productive operations.

Graph 5 shows the total hours accumulated by the "Sem Apontamento" operation in October of each harvest.

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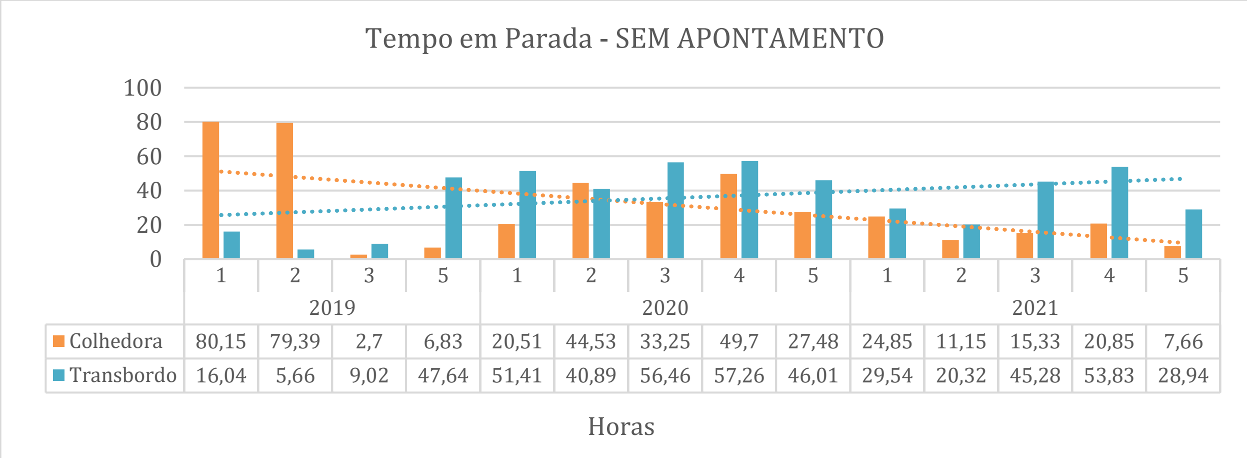
Graph 5 - Downtime per Operation



Source: The Authors.

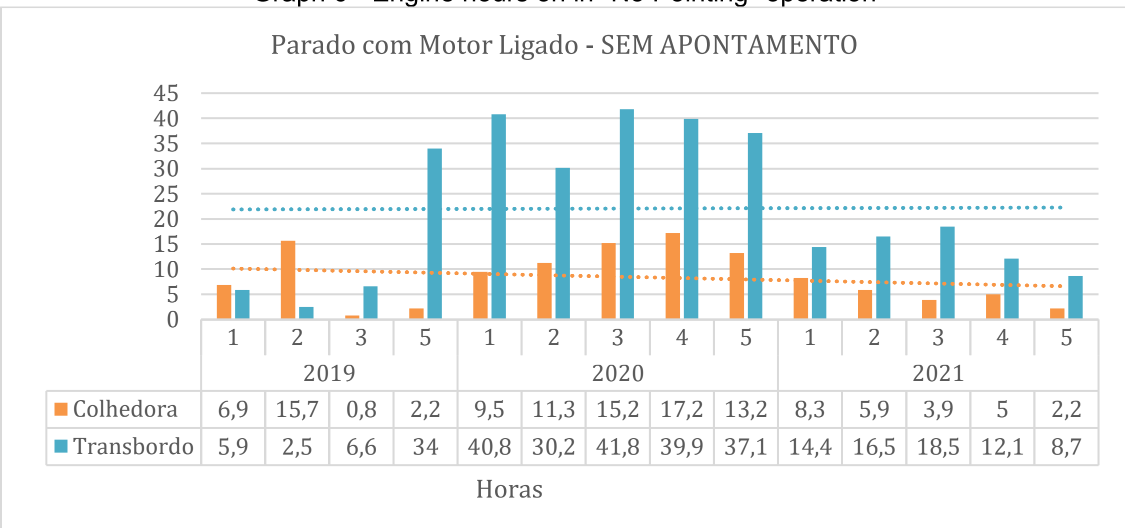
In the graph, it is observed that, in 2019, the number 4 cutting front is not referenced, due to the absence of this front in the sugarcane harvest during this period.

Another relevant point identified during the analyzed period is presented in Graph 6, where an aggravating factor is observed in the highlighted operation: the engine running rate while the equipment is in a state of stoppage.

This value is considerably significant for an operation that should follow the engine off routine.

This occurrence generates an important indicator: the diesel consumption of the equipment. It is worth mentioning that, among the costs of agricultural machinery, fuel and lubricant represent a range of 16% to 45% of the total costs of the operation.

Graph 6 - Engine hours on in "No Pointing" operation



Source: The Authors.

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By analyzing the percentage of engine started during the "No Pointing" stop operation, it is possible to observe the significant impact of this occurrence in relation to the other factors that cause engine idleness, also characterized by unproductive operations that require engine shutdown. In 2019, the operation of the engine on accounted for 30.1% of the total unproductive operations, followed by 59.9% in 2020 and 38.6% in 2021. These data indicate that the Agricultural Operations Center (AOC) has not performed efficiently over the years, failing to promote continuous improvements in the control of this occurrence of high consumption.

Throughout the historical collections, it was possible to highlight the importance of effective monitoring of agricultural mechanization (carried out through the on-board computers installed in the machines), with the responsibility of the COA sector. This monitoring, when well applied, can significantly increase operational efficiency by identifying and acting on opportunities to increase productive time, in addition to enabling conscious intervention in situations that require manual notes.

Active control by the COA, combined with the preparation of action plans that identify and address the main reasons for stoppages, especially in the case of the "No Appointment" operation, are essential premises for effective and results-focused management. Chart 5 illustrates that it took three harvests to achieve an improvement in the stoppage rate of the harvesters' "No Point" operation, which still remains above the market *benchmark*, which is around 2%. This scenario is in contrast to the rates observed in the Transshipment Tractor, which showed an increasing trend compared to the year of implementation.

DISCUSSION

In this article, based on RBS, it was possible to explore the growing presence of 4.0 technologies in farms and agribusiness organizations, with a wide range of innovative *hardware* and *software* that offer essential support for strategic decisions in animal and plant production practices. The application of these technologies enables real-time monitoring, which facilitates more accurate and sustainable adjustments, promoting greater efficiency and productivity. However, the sector still faces the challenge of integrating the different socioeconomic and geographical realities, so that access to innovations and the development of technical skills are democratized. To this end, it is crucial that technical and practical knowledge is disseminated in an equitable manner, empowering users from all regions and agricultural profiles.

The analysis of the case study reveals that, even in well-structured companies specialized in offering technological solutions, it is essential to adopt a robust plan for the dissemination of knowledge to all those involved. Such a plan should include both the implementation phase and continuous post-service monitoring, monitoring changes in teams and regularly measuring the ability of users to absorb and apply innovations. This approach is key to ensuring that technological advancement is sustainable and well-adapted to the operating conditions of each organization. With continuous monitoring, it is possible to mitigate the impacts of a high *turnover* of employees and ensure that the knowledge acquired is continuously reinforced, avoiding the loss of *expertise* and promoting greater autonomy in the use of technologies.

The exploratory research also identified an important gap in the state of the art: the lack of content focused on good practices in the use of 4.0 technologies, as well as models of use and lessons learned, which could strengthen knowledge management. This type of content is essential to increase the effectiveness of technological solutions, promote knowledge sharing among users, and drive innovation collaboratively. Although the literature and the agro-industrial market are largely supplied with services and applications for agriculture 4.0, there is a lack of practical and applicable materials, which represents an opportunity to develop a robust collection of knowledge management practices that guide the effective use of innovations.

CONCLUSION

The digital transformation in Brazilian agribusiness, driven by technology 4.0, is changing the way agricultural activities are managed, bringing significant gains in productivity, sustainability, and competitiveness. However, for this revolution to be inclusive and sustainable, it is necessary to promote a more effective integration between technology and training, involving universities, research centers, companies, and *startups* in initiatives that expand access to innovations and generate practical knowledge for users.

Throughout this article, the importance of a continuous knowledge management plan, which covers both implementation and post-sales follow-up, has been highlighted in order to ensure that users have the necessary skills to deal with constant innovations. This approach allows not only the technological updating of operations, but also the strengthening of human capital, creating a collaborative environment that is adaptable to changes in the sector.

Finally, strengthening the practical knowledge base, with a focus on good practices and use models, is essential for Brazilian agribusiness to make the most of the potential of Agriculture 4.0. In this way, it will be possible to build a more innovative, competitive, and sustainable ecosystem, which contributes significantly to the country's development and global food security.

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